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ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING: DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK

Volume I: Final Technical Report

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Analysis of Defects in Trouser Manufacturing: Development
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UNCLASSIFIED/UNLIMITED

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Apparel Quality Control; Apparel defects; Knowledge-based   119
Systems; Fabric defects

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EXECUTIVE SUMMARY

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SDAS uses information on the location and nature of the defect to identify the manufacturing operation causing the defect and displays possible causes and remedies for the defect. SDAS also has a provision to display the relevant construction specifications (MIL-SPEC) for the assembly operation causing the defect. Both FDAS and SDAS are implemented in Nexpert Object and are linked to a relational data base using Oracle. They run under both MS-DOS and Unix environments. Software manuals for using FDAS and SDAS have been produced.

FDAS is intended for use at the greige or finished fabric inspection station in a weaving plant. It can also serve as a backend to a vision-based inspection system. SDAS can be used by an apparel plant for the inspection of trousers.

About the Report: The final technical report is presented in three volumes. In Volume I (the present volume), the details of the research effort are discussed along with recommendations for additional research. Volume II is the software user manual for FDAS, while Volume III is the software user manual for SDAS.

CHAPTER 1

INTRODUCTION

The U.S. apparel industry is currently undergoing rapid changes to operate successfully in a highly competitive global market. One obvious way of being successful is to significantly improve the quality of domestic products. In addition to fetching a premium price, improved product quality accounts for customer satisfaction and consistent consumer demand.

The increasing emphasis in the apparel industry on "on-line" quality control highlights another important application of this research effort. Every assembly operation in trouser/apparel manufacturing adds value to the product. The detection of a defect and initiation of remedial measures right at the stage at which the defect occurs will mean not only fewer defective garments but also reduced wastage of production resources. Thus, there is a need to simplify on-line quality control procedures, to set up a formalized approach for tracking defects occurrence and to analyze their causes with the primary goal of instituting remedial measures.

Many apparel plants, as they function today in the United States, do not maintain an accurate record of quality performance on a day-to-day basis. A continuous tracking and recording of defects is essential to positively influence quality levels over an extended period of time. Quality records must be maintained not only for the plant as a whole but also for the various production equipment and individual operators.

Considering all the above factors, it is clear that there is a need not only to investigate the problem of defects in garment manufacturing but also to build an intelligent system that can record, identify and diagnose defects occurring in garment manufacturing.

1.1 Scope of the Endeavor

The primary objective of the research effort is to develop a knowledge-based system to analyze the causes of defects in apparel manufacturing and to suggest remedies to correct them. This would be a turn-key software product, with primary application to the domain of utility denim trousers (MIL-87062A). This area was chosen from the world of military apparel, keeping in mind the large numbers of utility trousers procured by the military every year, and the rigid construction specifications and quality norms that this procurement is to meet. In all, the domain of denim utility trousers constitutes a significant yet manageable, portion of the overall apparel market.

The research agenda was broken up into three broad phases. These divisions represent not only the executed chronological sequence but also the set of formally defined sub-stages whose results are useful in and of themselves.

Phase I: The first phase consisted of an in-depth investigation into the current practice of analyzing and classifying defects, including the economic impact of defects in trouser manufacturing operations. The observable factors of defects and their definitions were recorded. Typical con-

tractual requirements and established contract quality levels were studied. Also, general specifications such as description of the objectives and requirements of the product, and constraints/parameters of operations were noted. Applicable standards (MIL-STD-105D, MIL-I-45208) and classification schemes developed by major apparel manufacturers were utilized as guidelines. A critical review of past research in this area covering government publications, apparel journals and computer science and knowledge-based systems literature was performed.

Phase II: The second phase covered the development of a classification scheme and analysis paradigm for the whole range of defects and their possible causes and remedies. This phase was undertaken with the intended purpose of expressing the organized information in computerized form, and it included a ranking scheme for defects and a list of suggested remedies. Applicable specifications such as MIL-T-87062A which lay down quality norms for men's denim utility trousers, were used as the primary source of guidance. Selection of suitable hardware and software tools was also completed in Phase II.

Phase III: The third and final phase consisted of the implementation of the knowledge framework in software and testing for refinement and verification. Research in computer-aided defects classification/diagnosis in other areas of engineering was examined with the intention of adopting the useful concepts and techniques.

The finalized software product can be has been demonstrated to the research sponsor (the U.S. Defense Logistics Agency), other government agencies and the textile/apparel industry. Product documentation manuals are also available for delivery along with the software.

CHAPTER 2

OVERVIEW AND RESEARCH METHODOLOGY

This chapter is an overview of the next nine chapters. It provides a comprehensive account of the research project. Most of the section headings in this chapter correspond to an entire chapter in the subsequent pages of this report.

2.1 Current Defects Detection and Analysis Procedures

2.1.1 Denim Fabrics

Most producers of denim fabrics in the U.S. carry out 100% inspection at the finished folding stage. Since denims are made with indigo-dyed yarn, the question of greige fabric inspection does not arise in denim manufacture. Inspection at the finished fabric stage serves the following functions:

a) Elimination of fabric flaws that are unacceptable to apparel manufacturers, and consumers in general.

b) Tagging minor flaws. Usually, tags are used on one or both sides of the fabric to indicate the location of the fault to the spreader. Tags of different colors are sometimes used to convey information about the nature of the flaw.

c) Control of yarn and fabric quality on the basis of day-to-day recording of defect occurrences.

d) Sorting of fabric production in accordance with defect levels.

e) In some cases, sharing of fabric defects information with the apparel manufacturer. Defect statistics are recorded for each roll and each sort delivered to the garment manufacturer.

Fabric Grading Systems: The two fabric grading systems currently being used by the U.S. textile industry are the 10-point system and the 4-point system. Both systems identify defects, and assign a demerit point value for each defect, based on the seriousness of the defect.

The 10-point grading system assigns points for warp-way faults based on four standard imperfection sizes as follows:

Up to 1"	--	1 point
1" - 5"	--	2 points
5" - 10"	--	5 points
10" - 36"	--	10 points

Filling-way defects ranging from 5" to half the width of the fabric are assigned 5 points. Defects exceeding half the fabric width are assigned 10 points. No yard of fabric is assigned more than 10 demerit points no matter how bad or how frequent the defects are. The total number of defect points recorded is compared against the number of yards in the inspected piece. If the number of penalty points does not exceed the number of linear yards, the fabric is considered a *first*

quality fabric. If the fabric width is greater than 50", up to 10% more penalty points are allowed for a *first quality* classification. Also, greige fabrics that are to be subsequently printed are allowed 50% more penalty points.

The 4-point grading system also assigns demerit points to individual defects, but the basis for point assignment is different from that of the 10-point system. The standard point assignments for different defect extents are as follows:

3" or less	--	1 point
> 3" but < 6"	--	2 points
> 6" but < 9"	--	3 points
> 9"	--	4 points

Not more than 4 demerit points are assignable to a single yard of fabric; the total number of points are normally figured on the basis of 100 square yards. The acceptable level of quality can vary between buyers and sellers. Generally, not more than 40 penalty points are acceptable in 100 square yards of a first-quality fabric.

The 4-point system has the broadest base of support. In addition to the ASQC and the National Association of Sportswear Manufacturers, the Federal government and the AAMA have endorsed the 4-point system.

2.1.2 Finished Denim Trousers

The trouser manufacturing industry has no *standard* procedures for the inspection and grading of assembled trousers. The variations arise from the fact that no two plants producing a similar product experience the same type of defects with similar or nearly equal frequencies. The type and frequency of defects produced in a particular plant appear to be a characteristic of the production equipment used and the general manufacturing environment prevalent in the plant. Thus, while oil stains and loose threads may be the most common faults in one plant, these problems may not be that common in some other plant that produces the same or similar garment. The emphasis laid on the detection and correction of individual faults will therefore be different at different manufacturing plants.

There is also a wide variation in the resources employed for the detection and correction of faults occurring in the cutting and sewing processes. The number of persons dealing with Quality Control on the shop-floor varies anywhere between 0% and 18% of the production employees. There are also large variations in the human resources employed for in-process and finished garment inspection.

In general, inspection and QC procedures followed by a particular plant appear to reflect the quality requirements specified by the purchaser. Other factors that significantly influence the inspection and QC mechanism are the complexity of the garment's design, the type of production equipment available, and the volume of the production order.

In-process inspection is generally restricted to a percentage of the intermediate products; the exact percentage selected for inspection is, again, highly variable. In-process inspection is also

linked to the distribution of day-to-day defect generation in the sewing room. The QC Manager assigns inspectors to trouble spots. Inspection records are maintained by each in-process inspector, and rejected bundles are usually tagged and re-routed to the respective operator. Thus, wastage due to defects is minimized.

Finished garment inspection is usually carried out on the entire production run. The plant's output is classified, usually into three categories: *first quality garments, seconds* and *irregulars.*

2.2 Garment Assembly Defects vs. Fabric Manufacturing Defects

During the course of this research, it was found that yarn and fabric manufacturing processes accounted for anywhere between 30-70% of the defects in finished trousers. The exact contribution of the yarn and fabric manufacturing processes and the garment assembly process will depend to a large extent on the manufacturing process and the technology employed.

The large-scale use of open-end spinning machines and high-speed air-jet looms for yarn and fabric production, respectively, have considerably reduced the extent of yarn and fabric flaws seen in finished garments. At the same time, a few defects that are typically characteristic of the new technologies have been added to the list of possible flaws in the finished garments. However, in terms of overall impact on garment quality, these new types of defects are much less severe than the defects generated by the older manufacturing technologies that have been replaced.

In the apparel plant, too, new types of spreading and cutting machines and sewing equipment can contribute previously-unseen types of defects; however, the overall level of defects and their severity is always positively influenced by modernization of machinery or process. The relative contribution of the textile and apparel processes to defect generation is also very much a function of the garment type involved. Complicated garment design and construction coupled with tight sewing quality specifications will make it difficult to control cutting and sewing flaws within reasonable limits.

Due to the very large share of defect generation arising from yarn and fabric manufacture, it became clear during the early stages of the research that the project goals would be best served by splitting the effort into two software systems instead of one. One of the software products would deal exclusively with the tracking, analysis, classification and diagnosis of fabric defects. The other software product would perform similar tasks for defects arising out of the garment assembly process. While this decision to proceed with two simultaneous development efforts undoubtedly increased the volume of research work, any other alternative would not have led to the realization of the project goals.

Need for two software systems: Another major reason for having two sister software systems was the mutually exclusive utility of such software. Fabric manufacturers very seldom operate their own garment assembly plants, and almost always sell their product to independent apparel makers. Such textile plants would benefit from a fabric defects analysis system, but would not have any use for garment defects analysis software. Similarly, apparel manufacturers are rarely integrated from yarn spinning to garment manufacture. Their primary concern is about quality viola-

tions in the garment manufacturing process. They have no direct control over the correction of yarn and fabric defects. Consequently, they cannot use the fabric defects analysis software as an in-process quality control tool. However, they would be interested in gathering and reporting data on fabric defects to their suppliers.

A secondary rationale was the size and complexity of the overall software system. Two separate software systems, one for fabric defects analysis (FDAS) and the other for sewing defects analysis (SDAS), would certainly result in smaller sizes of each, and these would be easier to test, learn and use. Also, they could be much more easily customized to the needs of a particular manufacturing organization, since they were more precisely targeted in the first place.

The likely users of the systems may be classified into two broad categories. The first class of users are the fabric or garment inspectors, who will be using their respective defects diagnosis/classification systems repeatedly during the course of their work. The main function of the software in these cases is to serve as a recording device, and to flag the out-of-tolerance conditions that merit attention from technical personnel. The second class of users comprises the technical personnel themselves, who will be consulting FDAS or SDAS for corrective information pertaining to frequently occurring and difficult-to-diagnose defects. The latter group will be very much interested in the reasoning of FDAS or SDAS in coming to a conclusion. However, the first group of users may not be interested in all the details, which may slow down the rate of inspection.

2.3 Interviews and Interactions with Industry and Government

Two questionnaires were designed to receive feedback from the industry on fabric flaws and sewing defects. The questionnaires were intended to elicit information, in a structured way, from apparel industry executives about their experiences with tracking and controlling defects. It was hoped that the questionnaires would draw enough detailed answers to yield statistically meaningful information about problem areas, the economic implications of the various classes of defects and current industrial QC schemes.

The first questionnaire sought information on defect classification norms, in-plant testing and evaluation procedures (for fabric, thread and trim), the nature of fabric flaws, the nature of sewing flaws, the relative proportion of fabric versus sewing defects, the qualifications and experience of quality control personnel, and details of the quality control programs in place.

The second questionnaire sought information on the economic impact of different defects and defect classes. This information was sought for the manufacturing organization as a whole, to get a picture of price realization of defects and the overall economic impact suffered at different defect levels.

Over the course of the project, the members of the research team made trips to several apparel and fabric producers in Georgia and neighboring states. The impetus behind such visits was to get a first-hand idea of the production resources employed in the manufacture of military utility apparel, and to have technical discussions with their managerial and QC personnel. Among the fabric producers were Cone Mills and Swift Textiles, who manufacture a large percentage of

the denim sold today to apparel manufacturers. Apparel manufacturers included commercial vendors such as Levi Strauss, and military contractors such as Tennessee Apparel, Dowling Textiles and Coastal Industries. The research team also worked very closely with apparel manufacturing experts at the Southern College of Technology, the site of the Apparel Manufacturing Technology Center (AMTC). The software systems were largely based on the input received from such experts.

More details on this subject can be found in Chapter 3.

2.4 Fabric Defects: Knowledge Acquisition and Collation

FDAS (Fabric Defects Analysis System) is intended to be an identification and diagnosis system for defects encountered in woven fabrics. The system covers the common manufacturing defects occurring in greige and finished fabrics, including those in indigo-dyed denims. In its present form, FDAS is ideally suited for indigo-dyed denim fabrics. However, the system can be used by any weaving or finishing plant because it has the knowledge for the analysis of defects occurring in these processes. Classification and analysis of defect occurrences on a day-to-day basis will be helpful in maximizing the percentage of first quality production. The system can be located at the greige/finished fabric inspection station or at the tenter frame to record and classify defect occurrences on a continuous production basis.

The primary source of information on fabric defects was the expertise of the members of the research team who had a very strong background and understanding of the whole range of textile manufacturing processes.

Other sources of information used were the major Federal Specifications relevant to fabric and garment manufacturing and the defects arising therefrom (MIL-STD-1488F, MIL-STD-87062A, Federal Standard #4B), textbooks and an MS thesis on fabric defects. A detailed listing of all the references and sources of information can be found in Chapter 4.

An exhaustive listing of fabric defects was then compiled, together with all the different modes of occurrence of each defect in the fabric. For each defect, a thorough investigation was conducted on all possible causes: arising from the material itself, from the process, from poor organizational practices, etc. A set of feasible correction measures was also listed for each defect in its many manifestations. Since the industry currently uses several different combinations of machinery and processes to make the final denim product, there may be several plausible remedies that may be applied for a given flaw. Additionally, newer technologies which have assumed dominance in denim manufacture, such as open-end spinning and air-jet weaving, contribute their own unique set of defects.

In parallel with knowledge acquisition and collation, research was carried out to understand the latest developments in the design of knowledge-based systems for diagnosis.

2.5 Fabric Defects: Representation and Reasoning

After several attempts, a necessary, yet sufficient scheme of classifying fabric defects based

on their visual characteristics was developed. There were four major visual cues: the type of defect, the defect's direction in the fabric, the defect's mode of occurrence (in both warp and filling directions) and the appearance of the defect. It was found that all fabric defects can be uniquely classified using these visual characteristics which can be readily identified by human inspectors. Also, future attempts to develop a fully automated inspection s, /stem using a front-end consisting of a vision system would find it exceptionally easy to deal with this set of visual cues as output parameters[1].

This scheme is very simple and classifies the entire set of fabric faults into groups according to the four discriminating visual attributes. A single defect can occur in several groups, depending on the factors that caused it. Also, some groupings in the classification scheme may have very few defects, or even none (usually owing to physical impossibility). This is elaborated further in Chapter 4.

The representation chosen for this defects analysis software followed an associational model, because of certain technical limitations of a causal model (please see Chapter 5). Using the Nexpert Object shell from Neuron Data, Inc., the entities in the fabric defects domain were represented in a class-object hierarchy. The class hierarchies are very useful in structuring the knowledge base, and in making it modular. Also, when reasoning over this knowledge base using search, pruning techniques to arrive at quick decisions regarding defects work well with such a hierarchically structured representation.

First, FDAS assembles information about the current defect, as seen by the user. The user indicates the values of the salient visual features of the defect, mentioned previously. After receiving information on the visual characteristics of the defect, the software compiles a list of all possible fabric defects that share the particular visual description. It does this by rule-based search for that group of defects which all show the visual characteristics given by the user. FDAS now presents a precise description of each individual defect within this group, and allows the user to decide which description exactly matches the defect under review. This matching of defect description with the actual defect is the final step in the identification process. Having pinpointed the exact nature of the defect currently being analyzed, the software then displays an analysis of the defect by listing the possible causes and remedies.

The diagnosis information for FDAS is contained in text files in the computer. Once a defect is identified precisely, FDAS retrieves the appropriate diagnosis information file and displays it. This arrangement makes it very convenient for an organization to customize the diagnosis files according to its manufacturing process and needs.

2.6 Fabric Defects: Software Implementation of the Analysis Framework

A commercial knowledge-based system building tool called Nexpert Object® was chosen to be the main implementation vehicle for this research work. This type of "shell" allows the pro-

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1. At the recently concluded international textile machinery show (ITMA '91) in September, 1991, Elbit Vision Systems of Israel exhibited an automatic fabric inspection system. Coincidently, their classification scheme mirrors the one implemented in FDAS; thus FDAS can serve as a backend to the Elbit system to totally automate the fabric inspection process.

grammer to work at a higher conceptual level than conventional symbolic languages such as LISP. Nexpert Object has a wealth of tools for rule-based programming and a reasonably good object-oriented paradigm. It provides communication with database systems, requires little programming expertise, and is relatively inexpensive. For purposes of software development, its incremental compilation features are also very useful.

The second component of the FDAS software framework is the Oracle® database management system (DBMS). Tables within the database record the defect information communicated to it from the FDAS defects knowledge base (in Nexpert) during each diagnosis cycle. The database keeps a long-term record of defects, which can then be examined and analyzed to find out pertinent information regarding defects according to time period, material type, loom number, shift, etc. Such a database also permits a careful and quantitative evaluation of the beneficial effects of any improvements made in the manufacturing process or QC procedures.

FDAS consists of a class-object hierarchy of entities in the fabric defects domain, with rules to perform the deduction task and manipulate these entities. The class-object hierarchy in this representation is the chief basis for the separation of domain knowledge and control knowledge; two separate class hierarchies are used, one for the representation of fabric defects themselves and their attributes, and another for controlling the focus of the search process.

The reasoning method used with this hierarchical representation is search, using several techniques to accomplish early pruning. The overall rule base is grouped into three levels. The first level of rules tries to define in which defect "Type" category (**Point, Line** or **Area**) the defect falls, according to the input from the user. The search process then narrows the defects domain using the second level of rules to a group, or sub-class, of defects sharing the same or similar set of visual attributes. The last level of rules explores the match of every defect description in this group with the appearance of the current defect as interpreted by the user.

At every level, redundant search is minimized by taking advantage of several inference controlling mechanisms available in Nexpert to recognize the successful completion of a sub-goal, such as finding an appropriate sub-class of defects. Another feature of the classification scheme is that the degree of sparseness varies considerably. That is, some defect sub-classes have only a few defect descriptions, while other defect groups have twenty or more. In the case of the more crowded groups, the defects which lie within the group are further divided into appropriate sub-classes. While this poses one more question to the user, it reduces the overall complexity of the software.

The current size of FDAS stands at 450 rules, including those for communicating with the Oracle database. The size of the knowledge base is not unduly large, considering that it treats about 95 individual defects with a combined total of about 350 occurrence modes. The analysis/diagnosis time is less than 10-20 seconds in most cases, depending on the complexity of the fabric defect seen and the training of the operator. Because of this short cycle time, FDAS can be used on the shop-floor.

For the UNIX version of FDAS, a graphics interface based on the SunView window system has been developed. Using several levels of menus and pop-up panels to ask questions and to inter-

act with the user, this interface greatly simplifies the use of the software and reduces training time. For the DOS delivery version of FDAS, a similar menu-based user interface has been developed using Nexpert Forms.

FDAS is fairly complex, and adding new defects to the knowledge base requires some effort, especially to understand the details of the class-object representation and the rule levels. On the other hand, it is extremely easy to change the diagnosis information, which is independent of FDAS and is resident in text files. Such diagnosis modifications do not entail any interaction with Nexpert. This trade-off in complexity is reasonable; it is far more likely that an organization will tailor the system's advisory output to its manufacturing processes and parameters and much less likely that it will need to add newer defects to the system.

2.7 Sewing Defects: Knowledge Acquisition and Collation

SDAS (Sewing Defects Analysis System) is a knowledge-based software system meant for the identification and diagnosis of sewing defects encountered in the manufacture of utility denim trousers to military specifications. The system covers predominantly sewing faults. While SDAS is designed to work for the assembly sequences recommended for trouser manufacturing, it can be extended to cover defects analysis for other garment types with additional effort. Classification and analysis of defect occurrences on a daily basis will be helpful in maximizing the percentage of first quality production, operator assessment, machine monitoring and production planning. The system is currently meant for use at the finished garment inspection station; it can also be modified for working with only certain segments of the production process for in-process inspection.

Several books such as the "Apparel Manufacturing Handbook" by Solinger, and "Guide to Apparel Manufacturing" by Peyton Hudson were used initially to gain knowledge about the garment production process and to get acquainted with the design and manufacturing methods and the terminology. Military specifications dealing with utility trouser construction (MIL-STD-87062A), garment quality evaluation (MIL-STD-1488F) and seams and stitches (Federal Standard #751a) constituted a very important set of guidelines for delineating the garment defects domain. Some of these specifications, such as the construction sequences laid down in MIL-STD-87062A, had direct influence on the structure of the software. A complete listing of the references used for deriving knowledge about the trouser manufacturing process is provided in Chapter 6.

The most important sources for information relating to the analysis of defects were the apparel experts at AMTC. Regular meetings were held with the AMTC personnel for technical discussions and their opinion was sought extensively on several aspects of software design and implementation.

The classification of sewing defects centered around the location of the defect, the nature of the defect, and the relevant recommendations for such a defect. These classification criteria were found to be adequate to describe each defect uniquely and to advise on the defect's causes and remedies. One of the military specifications (MIL-STD-87062A) was directly incorporated in the SDAS software to provide a ready reference on the construction standards.

There are some manufacturing considerations unique to the construction of denim utility trouser that set it apart from the assembly of other garments. One of these is the extremely stiff nature of the fabric, which makes defects such as seam pucker not only relatively uncommon in assembly but also easy to contend with. Another is the very simple construction of the garment, which has far fewer operations than other trouser assembly sequences. This contributes to fewer chances of errors at pattern design and cutting, bundle mix-ups, etc. A third point of interest is the preponderance of double-felled double-lapped seams, which contribute to a large percentage of certain types of sewing flaws. These will be described in detail in Chapter 7.

2.8 Sewing Defects: Representation and Reasoning

The sewing defects classification uses a scheme which is structured around two main criteria: the location of the defect, and the nature of the defect. These are the two major visual cues that an inspector derives during the inspection of the garment. The "Nature of Defect" heading is further classified into an elaborate decomposition with several sub-classes such as Seam Formation Defects, Stitch Formation Defects, Garment Appearance Defects, Defective Trim, and so on. This classification has been fully developed for sewing defects in the current version of SDAS, and can be extended for specific defects in other categories, if deemed useful. The "Location of Defect" is the other major heading, sub-classified only for the complex structural elements such as the flies. There is also a specification hierarchy which contains construction norms, with the relevant specifications being referred to for each defect being classified by SDAS.

The hierarchy trees are expressed as class-object structures, for purposes of modularity and ease of testing and future modification. All defect classification entities and their groupings are classes, and their contents are the individual types of defects, the defect location, etc. This set of class-object structures also affords a measure of commonality for expressing defect analysis schemes for other garments, at a later time.

The external working of SDAS is as simple as that of FDAS. The user is presented with a pair of selection panels, one for indication of the nature of the defect and another for the defect's location on the garment. After receiving the important visual information from the user, SDAS proceeds to deduce the assembly operation responsible for such a defect, by a rule-based search for the manufacturing operation(s) that may be causing the defect. If more than one manufacturing operation could cause this defect, then further questions are posed to the user about the character of the flaw until an accurate conclusion can be reached. Once the assembly step has been pinned down, the type of defect is further analyzed to determine its exact origin and to decide if it had been caused by an operator or by the machine. For every defect, there is a generalized diagnosis available; also, if there are specialized remedial measures to be taken for that defect when seen at a particular location on the garment, these are readily displayed. As in the case of FDAS, the corrective measures are contained in text files, to facilitate their easy modification and customization. The Nexpert programs of SDAS deal with the representation of the defect knowledge, as well as the running of each diagnosis cycle.

After each diagnosis, SDAS asks if the user wishes to scan the construction standards defined in the MIL-STD-87062A for the operation to which the defect was traced. These assembly

specifications are also stored within SDAS, as class-object hierarchies. After some more search to determine the appropriate specifications, these are displayed for the user's reference.

2.9 Sewing Defects: Software Implementation of the Analysis Framework

As in the case of FDAS, the main software vehicle used to construct the SDAS program was Nexpert Object. Software development particularly benefited from Nexpert Object's sophisticated pattern-matching and logical operators, which were used extensively in the process of search. The second component of the SDAS software framework is the Oracle DBMS, with a table within it recording the defect information communicated to it from the main SDAS program written in Nexpert. This database keeps track of defects occurring over the long term, and can be examined at any time for crucial information such as quality levels for different periods and operators.

The class-object hierarchies in the SDAS partition the knowledge base into carefully designed segments, each dealing with domain knowledge about the defect location, defect type and manufacturing operations and controlling knowledge pertaining to the status of the diagnosis and other details of the current defect. However, the task of searching within the structure of defect entities to arrive at the right decisions pertaining to the origin and causes of a defect, and the rendering of suitable remedial advice is shared by the control expressions in the rules of SDAS.

The reasoning method in SDAS is search. Three large groups of rules carry out the fundamental tasks of deduction of manufacturing operation, synthesizing appropriate extraction parameters to retrieve the diagnosis and furnishing the specifications relating to this defect. The first group of rules attempts to define the manufacturing operation responsible for the defect, from the location details supplied by the user. The second group of rules is based on the "Nature of Defect" class-object hierarchy, and is designed to perform the simultaneous tasks of synthesizing and retrieving the appropriate diagnosis, and to do some initial search processes for finding the relevant assembly specifications. The third set of rules finally defines the relevant set of construction norms and displays them if the user so wishes.

SDAS is smaller in size than FDAS. It has 70 rules, including the ancillary control rules (apart from the three main groups described above) and the rules for writing defect information to the database. There is a trade-off, however, in that the class-object hierarchy is complex. As in the case of FDAS, the elapsed time for each diagnosis cycle is about 15-20 seconds, depending on the complexity of the defect and the experience of the operator. It is believed that this short consultation time reduces the inspector's effort in using the system and maximizes the time usefully spent on inspecting garments.

A graphics windowing interface based on the Open Look standards has been developed for the UNIX version of the SDAS program. Use of this interface simplifies the operation of SDAS and reduces the training required for inspection personnel. This interface uses the full complement of graphics facilities to present the user with a fast and easy way of classifying defects and obtaining diagnoses, without diverting too much time and attention from the primary task of inspecting garments. For the DOS version of SDAS, a Nexpert Forms character-based user interface has been developed.

SDAS has been designed to permit additions to the knowledge base. The diagnostics and remedial measures are stored in simple text files, which can be modified and added to with any text editor. However, SDAS itself is written in Nexpert, and suitable procedures must be followed to correctly manage any changes to the knowledge base.

2.10 Database Integration with FDAS and SDAS

On all four versions of the defect analysis systems (UNIX and DOS versions of FDAS and SDAS), the main defects analysis software written in Nexpert has been linked to a database. This interfacing of FDAS and SDAS with the respective database tables provides a way of recording defect occurrences in a systematic manner, while the defects analysis software sessions are in progress. The defects table(s) can then be cross-examined according to any selected group of query parameters to extract information relating to the extent of defects, their distribution within a period of time, major contributing factors, machine maintenance or setting problems. If a user desires to make modifications to the data written to the database, both the database schema and the str_cture of the rule triggering the write process have to be changed. The changes required in the rules are more difficult to make than the changes required in the database schema.

On UNIX, the communication with the database is completely controlled from the top-level graphical user interface, with full password prompting and the ability to selectively write to the database tables. In the DOS versions of these software systems, communication with the database is again transparent, but does not have certain features such as selective write. In this case, all the defect occurrences are recorded in the database.

The database interface is created using a database bridge, which is a special software that makes such program-to-database link easier. The database bridge has been used to write custom rules and database access procedures for controlling data transfer. Different copies of FDAS can be run on several UNIX machines at the same time, while recording defects data into one database via a network. This single, common repository of defects data collection from different inspection stations is ideally suited for a shop-floor inspection set-up. Similarly, the UNIX version of SDAS can be run in multiple sessions, communicating with a single database. However, due to an intrinsic lack of multi-tasking capabilities, the DOS versions of the analysis software cannot be easily made to work on a shared basis with a global database, without having to deal with complex DOS networking issues. Therefore, on a PC, FDAS will work with a single copy of Oracle loaded onto that machine. SDAS works in the same way.

2.11 Testing and Debugging

The development effort for the FDAS and SDAS software systems has been carried out exclusively on UNIX workstations, using a combination of Nexpert Object, C and the database software. This decision, during the early stages of the project, was driven by considerations of operating system power and sophistication, graphical user interface, etc. Because of the feature-rich programming environment, most of the testing and debugging has also been performed on these development machines.

FDAS went into a test cycle almost concurrently with software implementation. In addition, after the system was nearly complete, domain experts used actual defective fabric samples provided by commercial producers, to compare the system's analysis with their analysis of the defects. This procedure helped iron out a number of errors in the system. Improvement in functionality was another important benefit; much of the enhancement to FDAS, to incorporate specialized defects contributed by new but popular manufacturing processes, arose from such testing.

FDAS was ported to the DOS computer with few problems. Special presentation scripts were created with the Nexpert Forms utility, for use in a simple yet effective user interface. These did not entail any modifications to the FDAS knowledge base, which remains virtually identical to its parent knowledge base on UNIX.

Much of the testing and refinement of SDAS has been similarly accomplished on UNIX. In this case, most of the testing has been done in-house. In part, this was due to the very well-structured knowledge accumulated from consultations with the apparel manufacturing experts at AMTC as well as the paper specifications used by the military.

Moving SDAS to DOS proved more difficult than moving FDAS. Several external programs, written in C, are being used outside SDAS to perform some important functions that cannot be carried out from within the knowledge base itself. These required a complete re-compile on the DOS system, and in some cases, re-working of the programs to fit within the constraints of DOS. However, the knowledge base itself did not change drastically.

The additional capability of interacting with the database was developed later, for all the versions of FDAS and SDAS. The task was carried out first for the UNIX versions of the software, and subsequently for the DOS versions. The researchers encountered some difficulties on this latter task, owing to errors in the software supplied by the manufacturer. However, these problems were eventually overcome and both FDAS and SDAS were integrated with Oracle on the DOS operating system.

2.12 Generalization and Recommendations

Two software systems have been created, each working on both UNIX and DOS machines. FDAS covers the domain of defects in conventional denim fabrics, up to and including the finishing stage. SDAS covers garment manufacturing defects (mainly assembly defects) in the process of making denim utility trousers. Both software systems have been tested and refined. Both systems are meant for in-process use, at the appropriate inspection stage. While the software has all the functional capabilities originally planned, and more, both systems could have benefited from more industrial cooperation (especially SDAS).

FDAS can be more easily generalized than SDAS. Defects in most other types of fabrics (other than fancy fabrics such as damasks or figured jacquards) are not very different from those that FDAS already treats. In fact, some special defects arising from specific and newer manufacturing technologies and relevant to the denim manufacturing domain of FDAS may not be often

encountered when dealing with other fabrics. The major classification criteria in FDAS are visual clues which are common across the range of fabrics. Therefore, extensions to FDAS will deal more with alterations to the diagnoses for the various range of defects, and less with expanding the range of defects. Since modifications to the diagnosis files are relatively easy, generalization and/or customizing of FDAS is simple.

As in the case of FDAS, the diagnostics information of SDAS is contained in text files. Hence, users can customize the system output to their requirements without affecting the working of the rest of the system. The directories containing the diagnosis files have been structured to exactly mimic the defects class structure. Hence, it is easy for the user to make modifications at the right place. On the other hand, making modifications to the knowledge base itself requires more knowledge engineering when compared to FDAS. The basis of classification, viz., nature of the defect and the location of the defect is applicable to all garment types. However, since the possible locations are different for different garment types, the defect class hierarchies will vary.

CHAPTER 3

PRELIMINARY INTERVIEWS AND INTERACTION WITH INDUSTRY AND GOVERNMENT

At the beginning of the research project, a major objective was to assemble a knowledge base for the analysis of defects arising at various stages in the manufacture of a utility trouser. Other objectives included establishing fruitful contacts with experts and interested personnel in the industry for obtaining input and advice on the design and development of the software, and identifying test-bed sites for the final testing of the software.

The major sources of knowledge on fabric and garment defects domain were:

1. The questionnaires sent to the industry, and

2. Interaction with experts in academia and the industry.

The third important means of accumulating domain knowledge was a thorough review of the research literature in the area of fabric and garment defects. This is separately described for FDAS in Chapter 4 and for SDAS in Chapter 7.

This chapter presents the design of the questionnaire, an analysis of the responses, and selection of domains for building the knowledge-based systems. An overall picture of cooperation with industry and other sources over the course of the project is also presented.

3.1 Development of Questionnaires

An exhaustive questionnaire (please see Appendix A), covering the technical aspects and detailed categorization of defects arising during the manufacture of utility trousers, was designed. This 'Defects Questionnaire' covers the entire range of defects arising in fabric and garment manufacture including trim defects. The questionnaire was refined on the basis of the input provided by members of the AMTC Steering Committee.

The objectives of this questionnaire were to:

1. Obtain a list of defects frequently encountered, and establish a categorization.
2. Determine the extent of defects arising from different sources.
3. Evaluate current quality control practices in the industry, and the training imparted to personnel responsible for defects analysis.

To obtain specific data on quality control practices, the respondents were asked to provide information on their test methods, statistical quality control procedures and tolerances allowed for individual property parameters. The bulk of questions pertained to individual defects in five major categories: fabric, thread, buttons, zippers and lining materials. Further queries sought details

about quality norms, inspector training and formal exposure to QC practices, and some statistics on the price penalty caused by the generation of defects.

Another, comparatively brief, questionnaire was also developed to get high-level input on the economic impact of defects. This 'Economic Impact' questionnaire (please see Appendix A) did not go into the technical details of defects; instead it attempted to get a larger picture of the economic impact of defects involving defect generation within each product grouping, price realization therefrom, and loss of productive time due to re-working. It also asked for an approximate estimate of the contribution of fabric and assembly defects to overall defect generation.

3.2 Analysis of the Two Questionnaires

About 550 questionnaires of each type were mailed to apparel companies, under the auspices of the AAMA. The companies included the whole range of organizational sizes and products (not just utility trousers). However, the rate of return was disappointing. Only about 35 Defect Questionnaires and about 25 Economic Questionnaires were returned. Of these, less than 40% were really useful. Three major disqualifying reasons were inadequate effort at providing all the answers, enormous ranges to the data supplied (making it virtually useless), and contradicting information at different places in the same response (rendering it unreliable).

However, from the useful responses to the questionnaires, an effort was made to glean as much information as possible. Important findings are shown in Table 3.1. The table shows that any reduction in fabric defects can bring about sizable savings to apparel manufacturers, since fabric defects form a significant proportion (often half or more) of total garment defects. Price realization for seconds varied between 20% and 75%, but in most cases it was close to 40-50%. There were only three companies using computerized defect tracking of any form. Almost none of the organizations that responded had any formal training procedures instituted for Quality Control Inspectors.

Almost all companies had quality norms for trim articles such as buttons and zippers, but relied on their suppliers conforming to this set of requirements and doing their own testing. While fabric specifications were extremely tight and defect levels generally higher for companies manufacturing high-quality women's underwear, fashionable sportswear, and men's or women's outerwear, they were more relaxed for utility garments. Seam pucker predominated the list of defects associated with delicate garments, but caused less value loss in the case of denim trousers.

3.3 Plant Trips and Industrial Visits

Initially, several trips were made to fabric and apparel manufacturing plants in Georgia and neighboring states. These trips were meant to gain some preliminary knowledge about the state-of-the-art in manufacturing techniques and production processes, quality inspection procedures, etc., and to discuss the project with the technical personnel.

Table 3.1 Summary of the Analysis of Responses to the Questionnaire

	Average	Range
Number of responses	10	
% of Defective trousers	2	0.4-4
%Contribution of fabric defects	55	40-75
%Price realization for defective trousers	40	20-75
Annual sales (million $)	45	12-280

Computer assistance in quality control : Three of the 10 companies reported having computerized systems for collecting data on defects.

Training for Quality Inspectors : Most respondents did not have any formal training for quality inspectors.

Significant defects : 1. Shade variation in fabric
2. Missing warp threads
3. Filling defects
4. Soiled garments
5. Skipped stitches
6. Seam Puckering

These companies included denim fabric manufacturers such as Swift Textiles and Cone Mills, and apparel manufacturers such as Tennessee Apparel, Dowling Textiles, Levi Strauss, Oxford Slacks, Graniteville Industries and Coastal Industries. Some of the latter are general-purpose apparel manufacturers, but Coastal and Tennessee Apparel are almost exclusively defense contractors. In all these plants, the members of the research team got a good understanding of the production processes and the QC and inspection procedures.

Visits to Graniteville Industries, Swift Textiles and Cone Mills produced a wealth of information on denim fabric defects and inspection methods. They also provided an understanding of the commercial relationships between fabric suppliers and apparel makers, and the means used by the apparel manufacturer to provide feedback on defects seen in the fabric. The following general observations emerged from these visits:

1. The denim produced today predominantly comes from open-end spinning machines and air-jet weaving machines. These newer technologies have fewer, but very typical defects in their products, such as rotor yarn slubs, rotor piecings, etc.
2. Almost all the utility trouser manufacturers rely on the fabric supplier to inspect the fabric and to tag defects.
3. The spreading machine operator looks for these defect markers; there is no preliminary inspection at the apparel plant on the incoming fabric. There is usually no mechanism to provide feedback to the suppliers on consistently out-of-spec fabrics.
4. Most of the yarn indigo dyeing is of the ball-warp continuous range type.

An early visit to Tennessee Apparel was very useful in that it revealed the intricacies of some of the complex garments being manufactured for the military, and the special requirements of manufacturing apparel to meet military specifications. At Dowling and Oxford Slacks, the research personnel were exposed to other sectors of the commercial apparel market, such as the manufacture of hospital apparel and men's dress slacks, respectively.

Interaction with fabric procurement experts from Levi Strauss gave a good understanding of the typical fabric specifications and the sampling and testing practices followed by a large garment manufacturer. Meetings with the QC chiefs of Levi Strauss' main garment manufacturing facilities in Tennessee gave the research team an appreciation for the assembly sequences, inspection schemes, defects analysis and control being used by the company in the domain of utility trousers. All these details were noted and subsequently reviewed when drawing up the defect classification schemes and software design, so that the developed system would be compatible with the systems currently functioning in the apparel industry.

The last major plant visit was to Coastal Industries, a large military contractor in Selma, Alabama. The fruitful interaction with the management staff and top QC employees resulted in very useful guidelines for directing the software design and classification scheme for SDAS.

CHAPTER 4

FABRIC DEFECTS: KNOWLEDGE ACQUISITION

Knowledge acquisition is a critical step in the development of knowledge based systems. The task here has been to acquire as much knowledge about defects in fabric manufacturing from as many sources as possible, and to collate this information to realize the most comprehensive assembly of facts and relationships concerning defects, their occurrence, causes, and remedies. This chapter describes the knowledge acquisition process.

Another aim during this phase of the research has been to refine the research objectives, and to accurately define the specifications of the software system. Factors considered in the refinement process are possible applications, user profiles, further extensibility and response time requirements.

4.1 Sources of Knowledge on Fabric Defects

Several books and research publications contributed to the store of information on fabric defects. The major references and the areas covered by them are summarized in Table 4.1. Most fabric defects are found by visually inspecting the fabric for distinguishing features of a defect and by identifying the defect according to these characteristics.

The primary reference has been the work of Thomas [Thom 87]. This experienced Sulzer-Ruti engineer compiled a list of defects in grey fabrics which included probable causes and appropriate remedial actions. The compilation of the current knowledge base was begun with Thomas' work as the primary source. It was also used as the basis for identifying key characteristics of defects appropriate for classification. Based on other sources, the list of grey fabrics was made more complete, defects caused during chemical processing were added, and the earlier scheme of classification was refined. The lists of defects obtained from the questionnaires were used to verify the completeness of the compiled list with respect to fabric defects.

Several other books were used to add to and enhance the knowledge base accumulated by Thomas. Patel [Pate 74] discusses 235 fabric defects and their possible causes. In many instances photographs of defects supplement the defect descriptions. The issue of motivating personnel towards better quality control is also discussed. Hesse [Hess 52] has described the causes of fabric defects and loom stops in his work. An alphabetical listing of the defects along with photographs and explanation of the origin of some of the defects has been published by Hauptverband Baumwollweberei [Haup 63]. The German approach was also used in the Manual of Standard Fabric Defects in the Textile Industry compiled by the Graniteville Company [Gran 75], a major reference in the field. Fabric Inspection and Grading by Powderly [Powd 87] discusses different systems for fabric grading, quality specifications of both corporate and government institutions, and has an alphabetical list of defect definitions with some photographs. Grover and Hamby [Grov 60] provide an alphabetical list of fabric defects with textual descriptions. ASTM D 3990 -85 [ASTM 85] includes the standard names for the defects, various synonyms, causes of the defects and some

Table 4.1 Major References For Fabric Defects

Reference	Fiber Yarn	Greige Fabric Finished Fabric
[Thom 87]	X	X
[Pate 74]	X	X
[Gold 57]	X	X
[Gran 75]	X	X
[Gard 83]	X	
[Pali 83]		X
[Ratn 84]	X	

photographs. Government sources of information for textile defect analysis include the specifications developed by the military procurement divisions [MIL 84]. The MIL Specs are different from other literature in that they specify the standards and the tolerances for the materials and construction parameters. Many individual companies also have their own defect lists, defect descriptions and guidelines for grading and acceptability norms.

Several research papers and technical publications also provided more specialized insight into some defects on the list. Foster [Fost 52], Mahajan [Maha 86], and Balasubramanian and Sekar [Bala 82] have discussed the problem of filling streaks and diamond patterning defects in filling. The publications of South India Textile Research Association, and Ahmedabad Textile Industries Research Association give norms for quality and are good reference sources for the correct choice of process parameters [Ratn 88, Pali 83, Gard 83]. They also discuss the defects caused by incorrect parameters in spinning and weaving.

Table 4.2 shows the final list which consisted of 85 defects.

4.2 Fabric Defects: Occurrence and Causes

The literature reviewed on defects either just lists the defects alphabetically or classifies them according to the origin of the defect. Thus, most of the literature used either the manufacturing process causing the defect, or the severity of the defect as the basis of classification of defects. This is a serious shortcoming if one wants to refer to these sources to find the exact nature of a defect and to identify its origin, because the basic structure of knowledge in these sources *presupposes* precise knowledge of the particular defect under investigation.

An alternate way of classifying the defects in the textile materials is to base identification and analysis of a defect upon its visual characteristics. Also, there are other requirements of such a classification scheme: it should be hierarchically arranged to minimize the search process, and should be general enough to accommodate new defect descriptions added at a later date. A description of a necessary and sufficient set of these visual attributes of defects is introduced in the next chapter as a conceptual basis for representing the classification of fabric defects.

The same defect can occur in several ways on the fabric, owing to technological reasons. For example, a single bobbin of coarse yarn will result in a thin, single warp-wise streak running along the length of the fabric. If that bobbin is in the filling, the coarse yarn will manifest itself as a rectangular bar across the fabric. Because of this possibility of multiple modes of occurrence, a thorough technological analysis has been carried out for each of the 85 fabric defects, with a goal of achieving a complete map of every conceivable manifestation.

In the same vein, there may be more than one technological reason for a defect to occur in a certain manner. Depending on the mode of occurrence, every defect was fully investigated as to the possible human/machine/process/random causes which could contribute to its incidence. In every case where a defect has multiple causes, all of the possible causes are listed in the diagnosis file pertaining to that fabric defect. Each defect has its own diagnosis file, comprising a set of probable causes, and a listing of suggested remedies.

Point Defects

1. Burnt hole
2. Cockled yarn
3. Finger mark
4. Fuzz balls
5. Gout
6. Harness skip
7. Holes - damaged rolls
8. Holes - singeing
9. Knots in selvage
10. Large knots
11. Long knot tails
12. Mending hole
13. Neps
14. Tear drop

Line Defects

1. Abrasion
2. Broken end
3. Broken pick
4. Coarse yarn
5. Corded selvage
6. Crackers
7. Crease mark
8. Double end
9. Double pick
10. End out
11. Float
12. Hanging thread
13. Harness skip
14. Jerk-in
15. Kinky yarn
16. Looping pick
17. Misdraw
18. Missing pick
19. Mixed yarn - blend
20. Mixed yarn - Twist
21. Oily/dirty yarn
22. Reed mark
23. Rotary yarn piecing
24. Rotary Yarn slubs
25. Seam mark
26. Shade variation - yarn
27. Slack end
27. Slack pick
28. Thin yarn
29. Tight end
30. Tight pick
31. Uneven yarn
32. Warp burl
33. Warp streak
34. Yarn shade variation
35. Yarn slubs
36. Waste in filling
    (on loom)

Area Defects

1. Abrasion
2. Apron mark
3. Beam/fabric contami-
   nation
4. Bowed filling
5. Break out
6. Burnt holes
7. Coarse yarn
8. Color bleeding
9. Crease mark
10. Filling bar
11. Finishing bar
12. Hairiness
13. Hard size
14. Holes
15. Mat-up
16. Oil stain
17. Puckered fabric
18. Reediness
19. Rolled selvage
20. Rust stain
21. Selvage tails
22. Shade variation - fabric
23. Shade variation - yarn
24. Shrink mark
25. Shuttle smash
26. Soiled fabric
27. Specky dyeing
28. Temple mark
29. Tender spot
30. Thick place
31. Thin place
32. Torn cloth
33. Uneven fabric width
34. Uneven finish
35. Uneven yarn
36. Variable selvage dyeing
37. Wavy fabric
38. Wavy selvage
39. Wrong pattern

Table 4.2   List of Fabric Defects in FDAS

4.3 Literature Review: Computers in Other Interpretation and Diagnosis Tasks

The literature reviewed in this section will focus on aspects such as the stages in the development of a KBS, the decisions to be made at each stage and the criteria for making these decisions. Diagnosis systems from other fields will be used to illustrate the various points. The text by Waterman [Wate 86] provides a good introduction to the concepts and methods involved in building KBS.

Waterman provides guidelines to determine the appropriateness, feasibility, and justification for building a KBS for a specific problem. Slagle and Wick [Slag 88] also describe an analytical method of evaluating an application area. They propose a list of domain features, classified as essential and desirable features. These features are to be assigned weights and the chosen domain is to be assigned scores for each feature. The candidate domain will be assigned an overall value on a 0 -10 scale. They recommend a spreadsheet model to evaluate different domains.

The domain is then subject to careful analysis, to identify the main characteristics and special problems that will have a bearing on the decisions to be made at a later stage. Stefik *et al.* [Stef 83] have proposed a framework to characterize any problem in terms of complexity arising due to the size of the solution space, lack of certainty and stability of data, and lack of certainty of knowledge. They discuss 11 cases in increasing order of complexity and the techniques adopted to deal with each case. The techniques recommended to deal with a large solution space, such as *hierarchical partitioning* of the solution space and *generate and test* have been used in different systems to give a robust performance by minimizing the search [Laff 84, Thom 83]. The validity of the methods to deal with uncertainty is yet to be sufficiently established. Szolovits and Pauker [Szlo 78] have made some observations about the "extreme reluctance" on the part of both "experienced and novice physicians" towards "any formal computation of likelihoods." Quinlan [Quin 83] discusses the pros and cons of different methods to deal with uncertainty.

Most of the diagnosis systems serve as consultants to a human expert when needed, and are especially useful when the time taken by the system to come to a conclusion is not a serious constraint. Some systems, however, are used for tasks in which time is critical. Masui and Mc-Dermott [Masu 83] have developed AIRPLAN, which is a system for recommending launching and recovery of aircraft from a carrier after interpreting data about the current situation. They have discussed how consideration of the criticality of time affected their design decisions at different stages.

The next focus is on *conceptualization*, a phase wherein the activities of identifying the key concepts, relations, and specifying strategies and constraints related to the problem-solving activity, are performed. As an example, Kahn and McDermott [Kahn 84] identify approximately 20 key properties of mud such as density, viscosity and solid content during the conceptualization phase of their drilling fluid diagnostic system. The data that indicates whether any of these properties have values higher or lower than normal are used to determine the cause of the problem. Aikins [Aiki 83], in her system for diagnosis of pulmonary diseases, classifies diseases at the top level according to their effect as constrictive, restrictive, diffusive, etc. These classes are in turn categorized according to their severity into four subclasses.

Structures for organizing knowledge or concepts are now designed in the *formalization* stage. According to Waterman, this involves mapping the key concepts identified in the conceptualization phase into a formal representation. The two important decisions to be made here are the paradigm to be used for representing the domain knowledge and the inference mechanism to be used for manipulating the knowledge to solve the problem. Aikins gives the following criteria for both these decisions:

1. The chosen method of knowledge representation should explicitly show the function of every piece of information - whether it is knowledge about the domain or control knowledge.
2. The domain knowledge should be separate and should be easily manipulated by the inference mechanism rather than being built into it.
3. It must be easy to add or remove knowledge about the domain.
4. Multiple uses of the knowledge base must be possible.
5. The part suggesting the remedies must be separate from the diagnosis segment.

The two major methods of knowledge representation identified by Waterman are *rule-based* representation and *frame-based* representation. He includes both frames and semantic nets under frame-based representation. Minsky [Mins 75], who originated the frame idea describes it as a data structure representing a stereotyped situation with several kinds of information attached to each frame. Waterman's description of a frame closely corresponds to how it is implemented in practice: "a knowledge representation method that associates features with nodes representing concepts and objects. The features are described in terms of attributes (called slots) and their values." Many of the early systems, e.g., MYCIN [Shor 75], DENDRAL [Buch 78], ACE [Veso 83] and REACTOR [Nels 82], use rule-based reasoning; PIP [Kuli 80], and NUDGE [Gold 77] use frames; PROSPECTOR [Duda 84], GLAUCOMA [Szol 78], AM [Lena 76], and CENTAUR [Aiki 83] are systems that use a combination of rules and frames.

Aikins has summarized the strengths and weaknesses of frames and rules as representational paradigms. According to her, frames are suitable for knowledge representation when there are standard data patterns with a preenumerated range of plausible data values i.e., the conceptual entities in the domain can be described in terms of predefined frameworks of attributes and there is only a finite number of possible descriptors for each of the attributes. The main advantages of rules, according to Aikins, are uniformity and modularity. However, these advantages themselves can give rise to certain difficulties. Due to the uniform method of representation, the function of the rule is not explicit. Because of modularity, the indirect impact of adding or deleting a rule is not apparent. These and other disadvantages of rules can be overcome by the use of frames. A few other deficiencies in early rule-based systems have been overcome in recent systems. For example, Aikins mentions that in rule-based systems there is no control over the order in which the system will question the user. Most of the rule-based tools have an implicit control depending on the order in which the data is arranged in the rule. Nexpert Object, a KBS shell from Neuron Data, allows explicit control by assigning priority numbers to objects.

After the problem domain has been adequately and accurately represented by corresponding information structures, the task of using this representation to achieve a meaningful end is accomplished using some type of inference process. Problem solving tasks have been described dif-

ferently as *search* [Fike 80], *reasoning* [McCa 69], or *constraint satisfaction* [Fox 84]. Most diagnostic tasks, particularly in medicine, have been characterized as search. Systems that interpret the behavior of mechanical or electronic systems have been described as reasoning systems. Planning systems are described in terms of the constraint satisfaction metaphor. Simon [Simo 83] points out that all the three metaphors are simply different views of the same problem solving algorithm. Hence, the only clear distinction among problem solving methods seems to be based on the nature of knowledge employed by them - whether it is based on cause-effect relationships or just an associational model of related components of the system.

Associational models have been described as shallow, surface, compiled, or low-road, and causal models as deep, model-based, or high-road. Clancey [Clan 85] describes associational or heuristic knowledge as follows:

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A heuristic relation is uncertain, based on typicality, and is some-
times just a poorly understood correlation.  A heuristic is often
empirical, derived from problem solving experience.  Heuristics of
this type reduce search by skipping over intermediate relations ...
Intermediate relations may be omitted because they are unobservable
or poorly understood.
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The advantage of using associational knowledge which embodies the precompiled knowledge of the expert, in terms of speed and efficiency has been pointed out by Genesereth [Gene 84] and Fink, Lusth, and Duran [Fink 85]. It is also more modular as relationships between system components are not deep. It is the only option available when the human understanding of the domain is limited [Gene 84]. Bublin and Kashyap [Bubl 88] and others advocate causal model mainly for two reasons - their ability to handle novel situations obviates the need to preenumerate all possible system states, and they can offer a better explanation of their line of reasoning based on their deeper knowledge of the domain. There are certain serious handicaps to the causal models, e.g., the compiled knowledge of the expert cannot be embodied in them, and so they cannot employ shortcuts even for very common problems. Some systems such as IDT [Shub 82], IN-ATE [Cant 83] and GLAUCOMA [Szlo 78], use a combination of both model-based deeper reasoning and rule-based heuristic reasoning in their problem solving.

After establishing the most reasonable metaphors for representing the knowledge, specific mechanisms for problem solving have to be identified. Stefik *et al.* [Stef 83] offer guidelines for selecting a method of search depending on the domain characteristics identified. Several researchers have reported employing different techniques such as *generate and test* [Laff 84], *resolution theorem proving* [Gene 84], *belief updation by minimaxing* [Cant 83] and *simulation* [Benn 84]. Hierarchical classification of the hypotheses to make search more efficient is common in medical diagnosis systems [Thom 83, Szlo 78]. Here, category hypotheses describe groups of diseases that have some common features, the disease hypotheses describe individual diseases, and pathophysiological hypotheses describe the faults in the system causing the disease.

As far as implementation issues are concerned, there are a variety of software and hardware platforms available for implementing a knowledge-based system (KBS) for diagnosis. General purpose languages such as LISP have the advantage of flexibility when compared to special purpose tools. On the other hand, special purpose tools built specifically for developing KBS enhance the productivity of the knowledge engineer by several orders of magnitude. These tools are be-

coming less expensive, impose very few limitations on the knowledge engineer in knowledge representation, provide user-friendly interfaces, can communicate with or can be embedded into conventional software, and are increasingly available on a wide variety of personal computers and workstations. Freedman [Free 87] has evaluated 27 KBS building tools in terms of their main features. The features have been classified into syntax, semantic and pragmatic features and a summary of the evaluation is presented in three matrices. Gevarter [Geva 87] has developed a framework for classifying the attributes of a KBS building tool in terms of developer and user interface and compatibility with other software. He has also evaluated several of the available tools using the framework developed. The methodology developed by these authors is very useful, since KBS tools are being continuously upgraded and new tools are entering the market rapidly.

4.4 Literature Review: Human-Computer Interface

A friendly and easy-to-use interface is as important as completeness and accuracy of the system. The interface requirements for a system developer are different from the requirements for an end-user of the system. Many KBS building tools provide the programmer with a wide range of features to enable rapid development of the system. However, the same plethora of tools may clutter up the interface for the end-user and obscure the features essentially required for the utilization of the system. H˜ ˜ , developers of a software system should consider the user profile and customize the user inte. ace to meet the requirements and abilities of the user. Literature in the areas of design of m .us, dialogue and output windows, and constructive error messages are presently reviewed

Shneiderman [Shne 86] identifies the following seven as the key issues in practical implementation of human-computer interface:
1. Interaction style
2. Input techniques
3. Response Time
4. Output Organization
5. Error handling
6. Individual differences
7. Development of a theoretical foundation.

The relevance of these issues to the design of the user interface for FDAS is discussed in Chapter 4.

Menus are a popular means for selecting options/commands. This is because of several advantages: minimal learning effort, very little or no typing required, and structured decision making [Shne 87]. There are, of course, a few limitations, such as a need for a rapid response rate, screen space requirements and possible need to display a sequence of menus. Hierarchical menu displays overcome some of these objections. Several colors and large screen displays reduce user fatigue. Buttoned prompts, different cursor shapes/sizes, and blocking inputs serve to direct and guide the user about appropriate responses throughout an application.

Smith and Mosier [Smit 84] offer five high-level objectives for any form of data entry:
1. Consistency of data entry transactions

2. Minimal input actions by the user
3. Minimal memory load on the user
4. Compatibility of data entry with data display
5. Flexibility for user control of data entry

Extensive research has been carried out to identify factors that are critical for achieving the above objectives and, wherever possible, to quantify the effect of varying the factors. Researchers have found that semantically meaningful organization of items within a menu helps to reduce user errors considerably, compared to alphabetical organization [Lieb 82, McDo 83, Lee 80, McEw 81]. Shneiderman [Shne 87] emphasizes the need for using terms whose meanings are clear to the user. With the hierarchical breakdown of items into menus, the user is faced with the trade-off between width and depth, i.e., between the number of items to be displayed in a menu, and the number of levels of menus. Miller [Mill 81] chose 64 items that could be fitted into valid semantic hierarchies. Of the four different width-depth combinations tried, the lowest error rate occurred with eight items per menu. There is general agreement that 4 to 8 items per menu, with no more than 3 or 4 levels of menus is ideal for minimizing user errors. Miller's classic paper on short-term memory emphasizes the need for keeping the items for consideration at any time within the "magical seven plus or minus two" to maximize the information processing rate, and to minimize error.

Besides an hierarchical layout of the display, a rapid display rate is also an absolute necessity for avoiding user annoyance with menu-based dialogue systems. Miller [Mill 68] has found that on most tasks, users are willing to wait up to two seconds for a response without loss of patience. But on certain tasks, it was found that the user's expectation of the response time was as low as one tenth of a second. This is especially true for users who have some familiarity with the software, and this would be achieved by FDAS' users in a matter of days. Since FDAS' response is critical for the completion of a task and the user is to be paid on the basis of the amount of task accomplished, the user is not likely to tolerate any delay in system responsiveness.

Similar to the objectives for data input, there are quality criteria for the output of an interactive software system. Well-formatted output is critical for the user to derive maximum benefit from interactions with the system. As with the design of input windows, the task and user requirements are to be well understood for designing good output formats. Smith and Mosier [Smit 84] suggest 162 guidelines for the design of effective output information structures. Tullis has shown that data in structured format can be comprehended more easily than data in narrative form [Tull 81]. Consistent positioning of the output has been shown to improve comprehension and retention of data presented in the output [Teit 83]. Color graphics display has been shown to evoke positive reactions in the user, though the performance did not improve significantly [Tull 81]. If carefully planned, colors can be used to show important concepts such as status changes and different categories of items such as queries and messages. However, if not used conservatively, color may impede comprehension of data in the output.

Error display and handling is another critical area of human-computer interface design. Users commit errors while using a software system because of lack of knowledge or inadvertent slips, which are to be expected especially at the novice stage. Too generic or obscure error messages will be of no help to the user and may leave the user feeling frustrated or inadequate. Golden [Gold 80] and Dwyer [Dwye 81a, 81b] have proposed general guidelines for more helpful error

messages. To generate more specific error messages, very careful planning of input parsing strategies, and message generation strategies is required. Because of these requirements, the objectives in this area are difficult to achieve Specificity, positive tone, user-centered phrasing, and appropriate physical format are the general guidelines given by Shneiderman [Shne 87] for designing appropriate responses to user errors.

A well-designed user interface should also be able to partially adjust its modes of functioning, verbosity of output and contextual help features to conform to the standards and abilities of the user. This is usually somewhat difficult to achieve without a self-assessment on the part of the user, before the actual software commences its operation.

CHAPTER 5

FABRIC DEFECTS: REPRESENTATION AND REASONING

The design of the conceptual representation and its formal mapping into software constructs are covered in this chapter. The fundamental visual features used to identify and classify a defect are described. Following this, the procedures involved in the analysis and diagnosis of fabric defects using this software are discussed. Specific implementation issues are treated in the next chapter.

5.1 Classification Scheme

A woven fabric is a planar assembly with a finite width and a nominally infinite length. In case of the fabric having some flaw or imperfection, it (the defect) is likely to have a certain orientation and extent. Fabric defects can be classified on the basis of the following attributes:

1. *Type* of defect;
2. *Direction* and *Extent* of defect (with respect to the fabric);
3. *Repeating Pattern* of the defect along the two principal fabric directions (length & width);
4. *Appearance* of defect;
5. *Size* of defect;
6. *Location* of defect.

The descriptors used to characterize each of the defects according to these characteristics were listed. Some defect characteristics, such as *Type, Direction*, and *Pattern* had only a limited number of possible descriptors. These 'key' characteristics and their possible descriptors are shown in Figure 5.1. *Appearance* had almost as many descriptors as the number of defects. These three were the primary attributes forming the current defect classification and identification scheme.

The *Location* of the defect was found to be useful only for separating selvage defects from the rest of the defects. The *Size* of the defect was used only in some instances to characterize the defects. Therefore, these characteristics were not included in the list of key characteristics finally adopted for the system; on occasion, their descriptors were incorporated into the accepted visual attributes given above.

The defect characteristics with limited number of possible descriptors i.e., *Type, Direction, Lengthwise* and *Widthwise patterns*, were used to classify the defects into broad categories. For example, the *Type* defect characteristic has three descriptors: *Point, Line* and *Area*. Similarly, the *Direction* characteristic has five descriptors: *Continuously Along the Length, Partially Along the Length, Continuously Across the Width, Partially Across the Width*, and *No Preferred Orientation*. The intersection sets of all these categories divide the whole set of fabric defects into smaller subsets. Figure 5.2 shows the classification of area defects using the additional visual characteristics
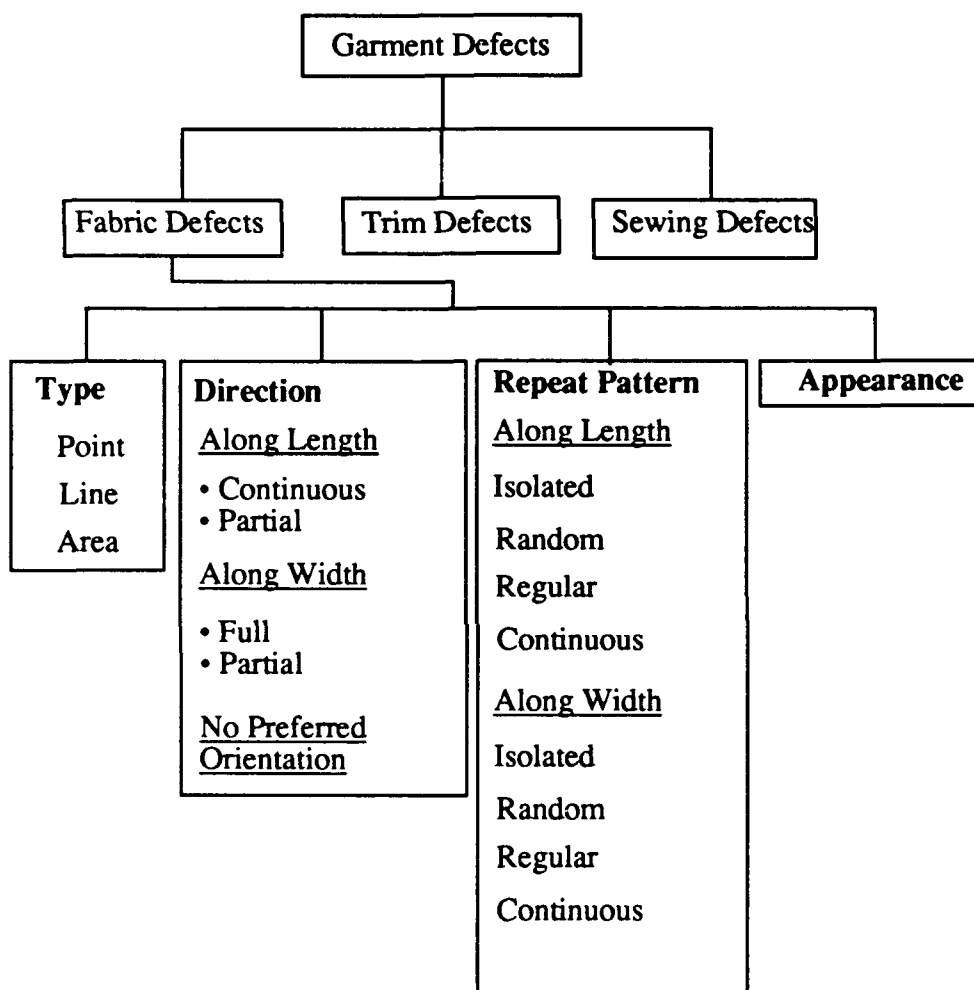
Figure 5.1. Schema of Garment Defect Classification

Direction, and *Length* and *Widthwise Patterns.* The other two subclasses based on *Type,* i.e., Line and Area defects are also broken down in a similar hierarchical fashion.

The nomenclature of the defect subclasses that is being used is shown in the box at the top of Figure 5.2, which is a pictorial representation of all the intersection sets of the classification categories. The acronyms used and their expansions are shown to the left of the figure. The general format of the subclass names is ZZ[Z]-$WX[X]FY[Y]$. ZZ[Z] represents the direction of defect with a two or three lettered acronym. The second part of the name, i.e., $WX[X]FY[Y]$, represents the lengthwise and widthwise patterns of the defect, respectively. W (for warp) and F (for filling) indicate lengthwise and widthwise pattern of the defect, respectively. X[X] and Y[Y] represent the widthwise and lengthwise patterns with one or two lettered acronyms. For example, the class name NPO_WIFR, stands for defects with No Preferred Orientation (ZZ[Z]), whose lengthwise pattern is Isolated ($WX[X]$), and widthwise pattern is Random ($FY[Y]$) (See Figure 5.3).

For illustration purposes, the classes corresponding to defects with no preferred orientation (NPO) are "sliced off" from the other classes in Figure 5.2. Figure 5.3 takes this slice and expands to show more detail; all the NPO classes and the individual defects in two classes viz., NPO_WIFR and NPO_WReFI, are shown. Whenever the number of defects contained in a subset was more than eight, as in NPO_WIFR, it was further divided using additional discriminating criteria such as the *Size* of the defect or other appropriate characteristics. Ultimately, the *Appearance* of the defect, which is unique to each element in a subset, was used to identify the defect uniquely.

The proposed scheme marks a departure from the traditional methods of classifying fabric defects as warp and filling defects or as spinning and weaving defects. The traditional methods presuppose knowledge of the exact identity of the defect and its origin, whereas this is precisely the information sought by a user from a defects analysis system. The scheme of classification in FDAS depends only on the visual attributes of fabric defects, which would be input by the user. The identity of the defect, its probable causes and remedies will be in the output of the system (FDAS).

5.2 Analysis of Defects: Diagnosis

During the formalization stage, the key concepts identified during conceptualization are mapped to paradigms for software implementation. The basic nature of the model chosen for FDAS is the associational type. Such a model would be fast and will have an advantage in modularity over a causal model, which requires building a model of the domain in software with all relationships between entities and components fully explored. An associational model for diagnosis requires pre-enumerative description of all possible defects in software, with search and appropriate selection during a diagnosis process. While this is inefficient, it is the only alternative because there are two major problems with building a 'deep' causal model:

1. Causal relationships between entities in the domain of fabric defects are not clearly established; this is a prerequisite for building a pure causal model.
2. The different operations up to and including garment manufacturing *viz.,* spinning, weaving, wet processing, and sewing are typically carried out at different locations and by different orga-

33
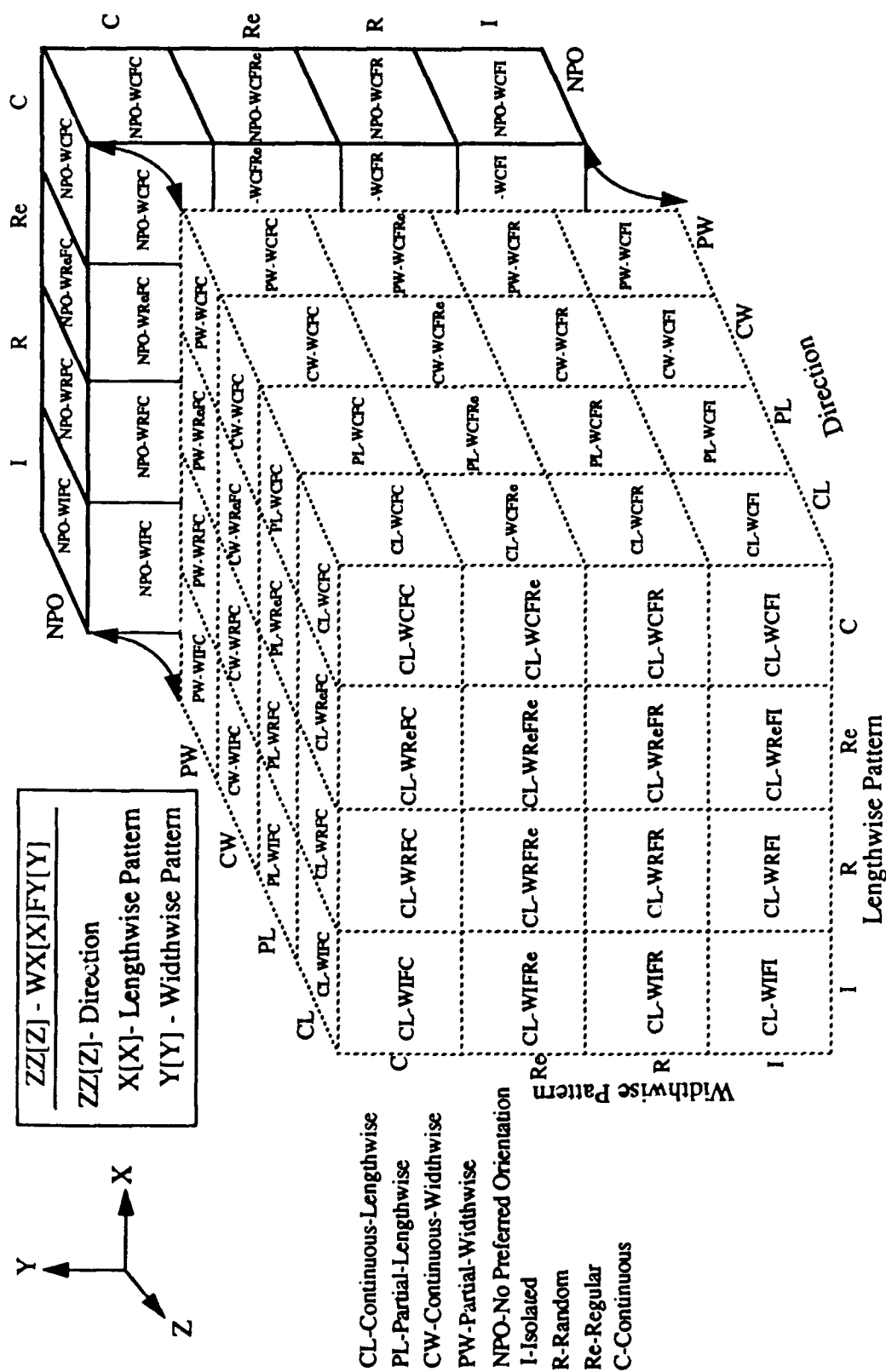
Figure 5.2   Classification of Fabric Defects According to Key Characteristics

NPO Direction

NPO

	C	Re	R	I
	NPO-WIFC	NPO-WRFC	NPO-WReFC	NPO-WCFC
	NPO-WIFRe	NPO-WIFRe	NPO-WReFRe	NPO-WCFRe
	NPO-WIFR	NPO-WRFR	NPO-WReFR	NPO-WCFR
	NPO-WIFI	NPO-WRFI	NPO-WReFI	NPO-WCFI

Widthwise Pattern

Lengthwise Pattern

NPO_WIFR

- **Stains/shade variation**

  Beam/fabric contamination
  Oil stains
  Rust stains
  Tender fabric
  Soiled fabric
  Shade variation in fabric dyeing
  Specky dyeing
  Size patches

- **Holes/torn fabric**

  Burnt holes
  Torn fabric
  Holes (Chemicals)

- **Knots/stretched warp yarns**

  Break out
  Hard size
  Mat up
  Size patches

- **Others**

  Abrasion-fabric mishandling
  Size patches
  Tender fabric
  Shrink marks

NPO_WReFI

Rust Stains
Size patches
Shrink marks
Shade variation in-
fabric dyeing
Specky dyeing

Figure 5.3   Further Categorization of Classes with more than Eight Defects

nizations. Consequently, all process parameters may not be available to a single user.

A hybrid formal representation is chosen for representing the entities in this domain, comprising *class-object hierarchies* and *rules*. Since the entities in the domain knowledge are hierarchically classifiable, it is possible to represent them using classes and objects. The use of class hierarchies has several advantages. The class hierarchies make the knowledge in FDAS highly structured. The relationship between different entities in the knowledge base becomes explicit. The part of the rule base using the entity descriptions for actual inferencing, and the part controlling the inferencing process are made clearly distinguishable by the use of two distinct class hierarchies.

The use of rules to represent domain knowledge helps in meeting certain important system requirements. The *if-then rules* are easier to understand than the other reasoning models and yield a more compact knowledge base. Due to uniform representation of knowledge, the modularity of the knowledge base is maintained. Hence in FDAS, the domain entities such as Bad Knots are represented using objects, types of entities such as Line Defects are represented as classes and rules are used for reasoning.

The number of defects in the current version of the knowledge base is 85. Since a defect can occur in several different modes (see Figure 5.4), there are more than 350 solutions to be considered. For dealing with large solution spaces, Stefik [Stef 83] suggests hierarchical classification of the hypotheses space as the first strategy to be tried. The entities in the current domain are *hierarchically classifiable*, and have common characteristics. Therefore, a process of searching through classes of defects by matching user descriptions with the class attributes, and pruning classes of defects early during the search, was chosen.

Some defects may belong to more than one class. For example, a coarse yarn will appear as a line defect if it is in the warp direction whereas it will appear as an area defect in the filling direction. *Multiple inheritance* allows any object to be an instance of more than one class, and inherit the properties of all the "parent" classes. Hierarchy of classes, with multiple inheritance, was chosen as the method of representing different categories of defects in FDAS [Srin 90].

5.3 Selection of KBS Software Tools

Once the key concepts in the domain and the paradigms best suited to represent them have been identified, they have to be implemented on a computer for practical use. Prior to system development, the software tool best suited for implementation must be selected. The different considerations which guided the tool selection are discussed here.

The first decision to be made is whether a general purpose language or a special purpose KBS tool is to be used for implementing the system. Once this decision is made, the specific language or the tool can be chosen. This is an important decision as the performance and the cost of the system will depend to a great extent on the chosen tool. The task and the domain requirements enumerated in Chapters 3 and 4 have to be matched with the capabilities of the tools in making a choice.
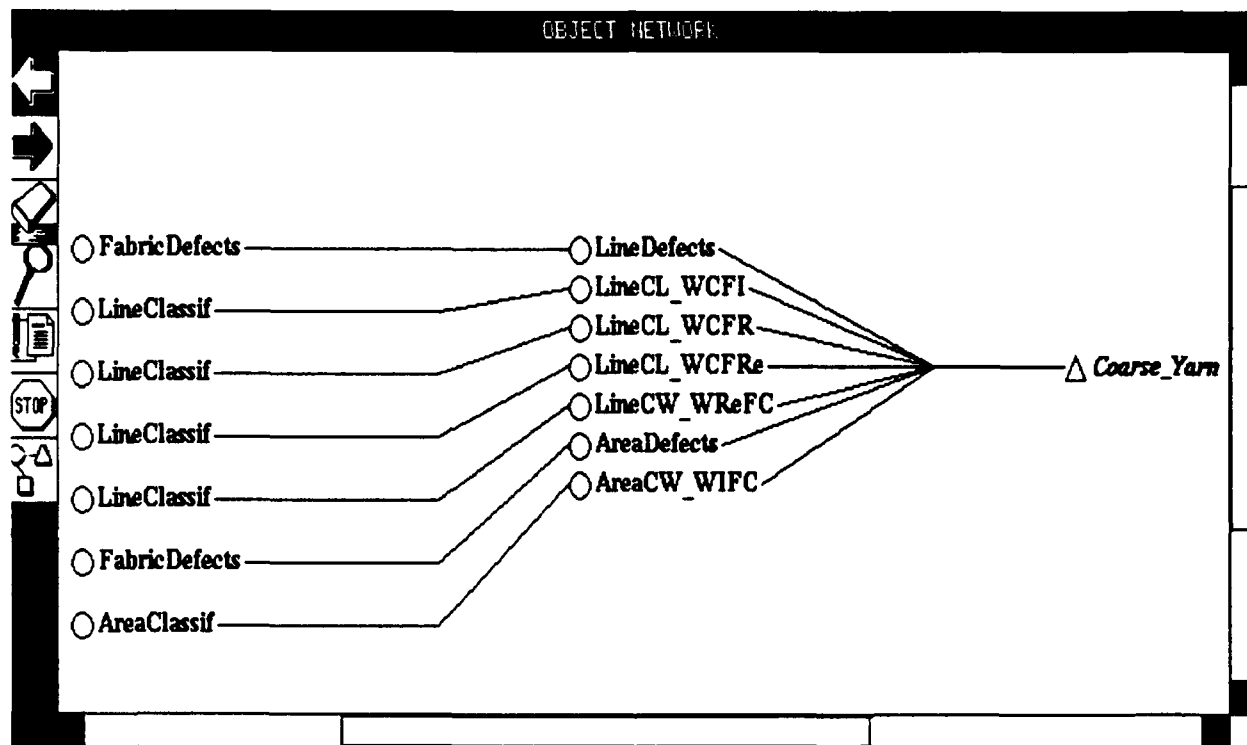
Figure 5.4 Different modes in which a Coarse Yarn Defect can occur in a fabric

Languages used for AI applications, such as LISP, are continuously enhanced through object-oriented representation, through their own programming environments such as multiple windows, and offer the advantage of flexibility in terms of system design. On the other hand, elements such as the inference engine, database interfaces and easy-to-use development environment have to be programmed anew, at least once, when a language is used. Features such as these are readily available in most of the commercial KBS building tools. This allows the system designer to concentrate on knowledge acquisition and representation, reducing the time required for system development. In other words, the system designer can think at the higher conceptual level of domain entities and relationships to be represented, than at the lower level of representational medium. Some KBS building tools provide the user with a rule-specific or object-specific editor, which makes it possible for the user to add to the knowledge base easily. For any system expected to be used by a large number of users, especially those without proficiency in programming, such easy modifiability is essential. These tools are increasingly available on a wide variety of computers, and some of them allow the same knowledge base to be used across different computers. Hence, using a KBS building tool for system development reduces the development efforts and the time required. Considering the above factors, it was decided to use a KBS building tool for developing FDAS.

Several commercially available tools for the development and use of KBS applications run only on personal computers, and support relatively small knowledge bases. Since the chosen task requires relatively large amounts of knowledge about different materials and processes involved in the manufacture of fabric and apparel, only more powerful tools, capable of supporting knowledge bases with 1000 rules or more without loss of robustness were considered. The chosen method of representing different categories of defects was class hierarchies with multiple inheritance . Therefore, it was essential that the chosen tool provides for object-oriented representation. ART [ART], KEE [KEE], Knowledge Craft [Know], Nexpert Object [Nexp], PICON [Pico], and ESP Frame Engine [ESP], support object-oriented representation well. Personal Consultant+ [PC+], S.1 [S.1], and KDS [KDS] are other tools that support object-oriented representation without some features such as selective inheritance or demons.

Since FDAS is intended for wide use in the textile/apparel industry, it should work on as wide a range of machines as possible. Compatibility with already available machines will make the system more readily acceptable to the user. ART, KEE, Knowledge Craft, Nexpert Object, Personal Consultant+, and S.1 are the only tools, among those mentioned above, meeting this requirement. Of these, only Nexpert Object and Personal Consultant+ have run time versions requiring fewer than 640 KB of memory, the current RAM accessability limit imposed by MS-DOS.

Mettrey [Mett 87] observed that "the use of object-oriented programming in the environment provided by ART, KEE, and Knowledge Craft requires proficiency in LISP in order to develop the required methods." Although rich representational methods are required, a user without much programming knowledge should be able to implement them. Creating and modifying objects in Nexpert Object requires some learning, but does not require any proficiency in programming. Similarly, it is easier to tailor FDAS for working with other types of software if it is based on a common language such as C. KEE and ART are LISP-based shells; it is difficult to find good LISP programmers when compared to finding programmers conversant in a traditional language such as C or Pascal.

Another very important factor is price. Nexpert Object costs from half to a fourth of the cost of environments such as ART and KEE. All these factors favored the selection of Nexpert Object. Other advantages of this software tool for building KBS are facilities for rapid prototyping (such as incremental compilation), simple links to relational databases such as Oracle or dBaseIV and hypertext tools, consistency maintenance between different editors, etc. A KBS built using Nexpert Object can call an external program or can be called from an external program; this kind of total integration with other software is absolutely essential, since a defect analysis system need not be a stand-alone system in a manufacturing enterprise. Text files, graphical files and scanned raster files can be displayed at any point during a session, using a simple "Show" command. This feature may be very useful for future versions of FDAS, in which textual descriptions of the defects can be replaced by pictures. Knowledge bases are portable across several supporting hardware platforms, which makes it possible to do the development work on a powerful Unix workstation, and makes the same knowledge base available on common computers such as IBM PCs and Macintoshes.

The inference engine built into Nexpert Object uses an efficient "opportunistic search", employing a combination of data-driven and goal-driven approaches. This is possible because the same set of rules can be used both in forward chaining and backward chaining modes without any modification. This enables the user to describe an unidentified defect, based on its visual attributes and let the FDAS determine what the defect could be (forward chaining). This type of usage is the primary functional mode for FDAS. Alternatively, the user could suggest a defect to FDAS and let it find out if the defect is present (backward chaining). However, this type of reasoning is not used because FDAS' typical usage is in the opposite direction: a diagnosis session is triggered by the user only when an unknown defect is seen and classification/diagnosis is desired.

CHAPTER 6

FABRIC DEFECTS: SOFTWARE IMPLEMENTATION OF ANALYSIS FRAMEWORK

This chapter presents the details of the software development of FDAS based on the knowledge representation and the reasoning processes. In FDAS, the domain knowledge is represented using a hierarchy of classes and objects, and reasoning is implemented using rules. The implementation of the class hierarchies and rules is explained and illustrated with three test cases.

6.1 Class-Object Representation

The broad conceptual classification of fabric defects, with the primary visual attributes of the defects shown as sub-classes was discussed in Chapter 5 (Figure 5.1). Some changes and additions to this conceptual class hierarchy were made during the implementation of FDAS. To separate domain knowledge and control knowledge, two separate class hierarchies are used in FDAS, one for representing fabric defects and another for controlling the focus of the search process.

Figure 6.1 shows the highest level classes of the two hierarchies; Figures 6.2a and 6.2b show parts of the two class hierarchies and illustrate their structures. Circles represent classes, squares represent slots or properties of the classes, and triangles indicate the objects or instances of the classes. The filled squares indicate properties with 'meta-slot modifications'. These meta-slot modifications are basically property modifiers, and can be used for specifying initial values or for invoking demons for performing actions such as changing inheritance dynamically. Another valuable application of a meta-slot modification is to override the Nexpert Object default query about any object ("what is the value of ...") and make it more specific and meaningful.

The class hierarchy used to represent different classes of fabric defects is shown in Figure 6.2a. The slots of the class *FabricDefects* are *Type, Direction, LengthwisePattern, WidthwisePattern*, and *Appearance* (These attributes are shown in alphabetic in order in Figure 6.2a which is the default order in Nexpert Object output). The Point, Line and Area defect subclasses inherit these slots as shown in the figure. In addition, they also have a slot *presence*, which is a Boolean to indicate whether a defect belonging to that subclass is present in the fabric. The inheritance continues down to the next level of individual defects. For example, *Bad_Knot*, an instance of *PointDefects*, inherits the slots *Type, Direction* and so on, as shown in the figure.

Slots such as *group, importance* and *value* are inherited by *Bad_Knot* from the *PointClassif* subclass shown in Figure 6.2b. The slots of objects in this second class hierarchy, *FabDefectsClassif*, shown in Figure 6.2b, do not contain any information about the defects, *per se*. However, the values of these slots are used to guide the search. The main requirement for avoiding redundancy in searching is to prune all the defects and defect classes which can be discarded based on the already known data. Classes *PointClassif, LineClassif*, and *AreaClassif* (short for Point, Line and Area Classification, respectively), inherit the slots *group, importance,* and *value* from *FabDefectsClassif*. The *group* slot is used to prune whole sets of defects, which do not have the same
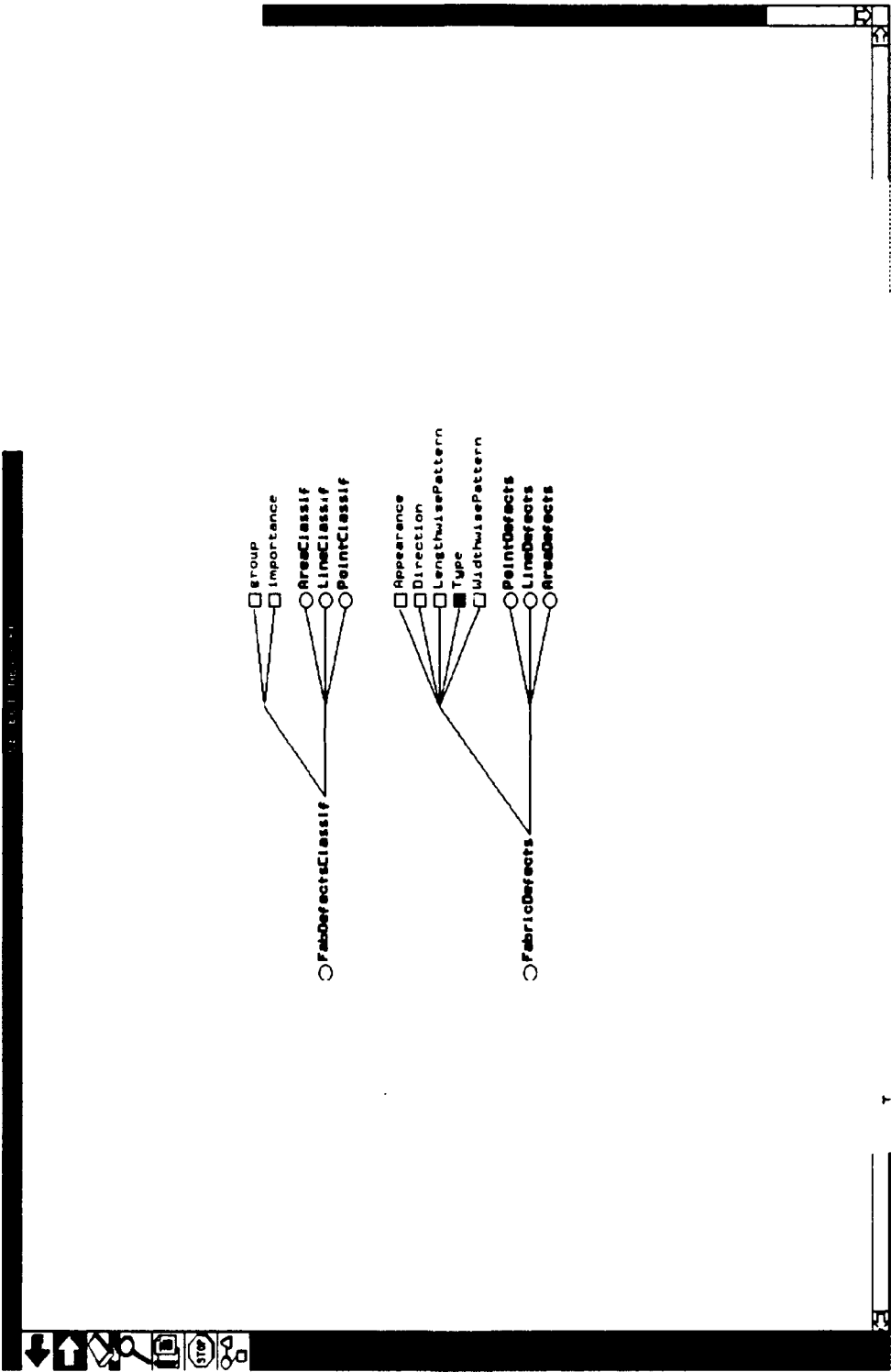
Figure 6.1 Top Level of the Two Class Hierarchies in FDAS

DEFECT HIERARCHY

FabricDefects

PointDefects
LineDefects
AreaDefects

Appearance
Direction
LengthwisePattern
Type
WidthwisePattern

Appearance
Direction
LengthwisePattern
presence
Type
Value
WidthwisePattern

Bad_Knot
Burnt_Holes
Cockled_Yarn
Finger_Mark
Fuzz_Balls
Gout
Harness_Skip
Holes_Damage_from_Rolls
Holes_from_Singeing_Sur
Knots_in_Selvedge
Mending_Hole
Neppy_Fabric
Tear_Drop

Appearance
Direction
group
Importance
Kind
LengthwisePattern
presence
Type
Value
WidthwisePattern

Figure 6.2a   Class Hierarchy for Representing Fabric Defects
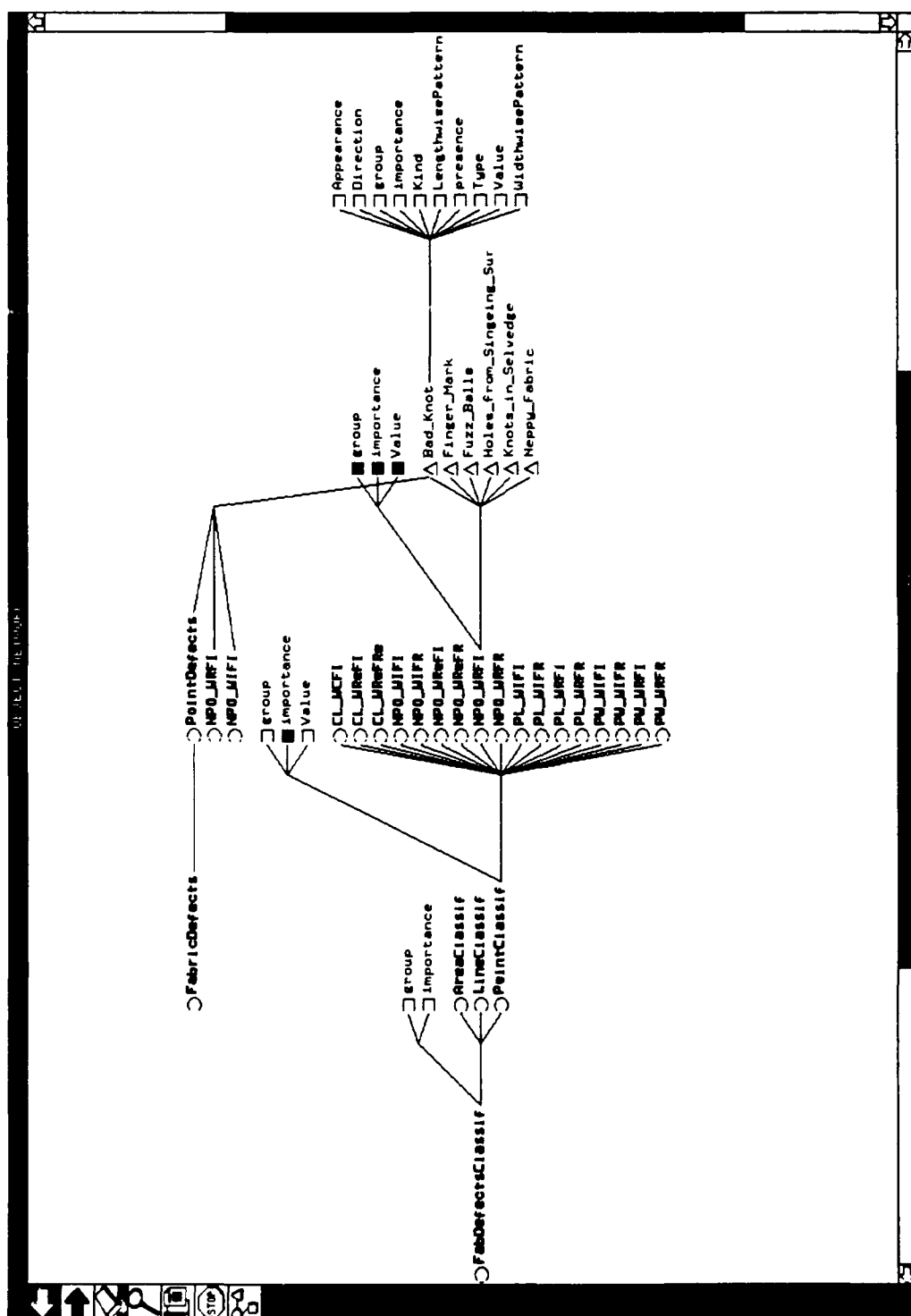
Figure 6.2b Class Hierarchy for Inference Control

identifying group of visual attributes matching those given by the user as characteristic of the defect being observed. The *importance* slot is used to focus the search only on that group of defects which remains under consideration after initial pruning.

The intersection sets representing all possible combinations of Directions and Lengthwise and Widthwise Patterns, named as shown in Figure 5.2, form subclasses under *PointClassif, Line-Classif*, and *AreaClassif*. Individual defects such as *Bad_Knot* and *Missing Pick* are instances of the subclass corresponding to the intersection set to which they belong. For example, in Figure 6.2b, *Bad_Knot, Finger_Mark, Fuzz_Balls*, etc., are instances of the subclass *NPO_WRFI*. An individual defect may belong to more than one intersection set owing to technological reasons, and hence can inherit the slot values from any of the corresponding subclasses. Shown at the top of Figure 6.2b, *Bad_Knot* is an instance of three classes, *i.e., PointDefects, NPO_WRFI*, and *NPO_W-IFI*.

Another mechanism called 'context linkage' available in Nexpert Object is used to establish which of the set of defects are to be considered once a defect sub-class is selected according to the user's input specification of a defect's visual characteristics. This leads to great economy of time in the actual diagnosis process, since only a small active set of defects is considered instead of the system's inference engine ranging over the entire domain of defects to check if they indeed could be present and exhibit this particular visual signature.

6.2 Three-tier Rule Base

As described in section 5.2, hierarchical classification of the fabric defects domain, with early pruning, was identified as the most suitable means for efficiently searching the defect that matches the user's description. This strategy is implemented using three levels of rules for progressively narrowing down the domain to be searched by pruning the defects (and defect classes) which do not match the user's description, early in the search. FDAS employs the strategy used in many medical diagnosis systems, that of 'category hypotheses' to identify homologous groups of defects (or diseases) and 'defect hypotheses' to identify individual defects (or diseases). The first two levels of rules identify progressively narrower subgroups of defects, and the third level rules are used to identify the individual defect out of the residual smallest subgroup identified by the first two levels as most relevant.

An example of a set of rules for identifying a Bad Knot is shown in Figures 6.3a. The working of the rules is shown in Figure 6.3b, which is a transcript generated by FDAS during its working and written to a file at the end of the session.

Level One Rules. At the beginning of the session, FDAS queries the user about the fabric defect *Type*, i.e., Point, Line or Area. Depending on the user's response, it will ask further questions about the specific defect's *Direction, LengthwisePattern* and *WidthwisePattern*. For example, suppose the inspector sees a Bad Knot, he/she describes the defect *Type* as "Point", the *Direction* of the defect as "No Preferred Orientation", *LengthwisePattern* as "Random", and *WidthwisePattern* as "Isolated". The data volunteered by the user are filled into appropriate slots. This part of the inferencing is shown in Section A of Figure 6.3b. The *Type* of the defect - Point, Line,

LEVEL 1 : Rule 54
If |**FabricDefects**|.**Type** is *"Point"*
Then **PointClassif** is confirmed.
And |**LineDefects**|.**presence** is set to *FALSE*
And |**AreaDefects**|.**presence** is set to *FALSE*
And **LineClassif.group** is set to *FALSE*
And **AreaClassif.group** is set to *FALSE*

LEVEL 2 : Rule 48
If there is evidence of |**PointClassif**|
And |**PointDefects**|.**Direction** is *"No Preferred
Orientation"*
And |**PointDefects**|.**LengthwisePattern** is *"Random"*
And |**PointDefects**|.**WidthwisePattern** is *"Isolated"*
Then **NPO_WRFI** is confirmed.
And |**PointClassif**|.**group** is set to *FALSE*
And |**NPO_WRFI**|.**group** is set to *TRUE*
And 100 is assigned to |**NPO_WRFI**|.**importance**

LEVEL 3 : Rule 3
If there is evidence of |**NPO_WRFI**|.**group**
And there is evidence of **Knot_Tails_Too_Long**
Then **Bad_Knot.presence** is confirmed.
And <|**PointDefects**|>.**presence** is set to *FALSE*
And Show "causes/knots_long_tails"
@KEEP=TRUE;@WAIT=FALSE;

Figure 6.3a   Three Levels of Rules for Bad Knots - a Typical Point Defect

SECTION A
Filling Slots With User Volunteered Data

FabricDefects.Type is set to *Point*
PointDefects.Direction is set to *No Preferred Orientation*
PointDefects.LengthwisePattern is set to *Random*
PointDefects.WidthwisePattern is set to *Isolated*

SECTION B
Level One Rule

Condition **|FabricDefects|.Type** is *"Point"* in rule 54. (True).
Rule 54 is set to true
PointClassif is set to *True*
RHS: **|LineDefects|.presence** is set to *FALSE* in rule 54
LineDefects.presence is set to *False*
RHS: **|AreaDefects|.presence** is set to *FALSE* in rule 54
AreaDefects.presence is set to *False*
RHS: **LineClassif.group** is set to *FALSE* in rule 54
LineClassif.group is set to *False*
RHS: **AreaClassif.group** is set to *FALSE* in rule 54
AreaClassif.group is set to *False*

SECTION C
Rejection of Discarded Subclasses

Rule 8 is set to false
CL_WCFI is set to *False*
Rule 9 is set to false
CL_WReFI is set to *False*
. . . .
. . . .
. . . .
Rule 46 is set to false
NPO_WReFI is set to *False*
Rule 47 is set to false
NPO_WReFR is set to *False*

SECTION D
Level Two Rule

Condition there is evidence of **|PointClassif|** in
rule 48. (True).
Condition **|PointDefects|.Direction** is *"No Preferred*
Orientation" in rule 48. (True).
Condition **|PointDefects|.LengthwisePattern** is
"Random" in rule 48. (True).
Condition **|PointDefects|.WidthwisePattern** is
"Isolated" in rule 48. (True).
Rule 48 is set to true
NPO_WRFI is set to *True*
RHS: **|PointClassif|.group** is set to FALSE in rule 48
PointClassif.group is set to *False*
RHS: **|NPO_WRFI|.group** is set to *TRUE* in rule 48
NPO_WRFI.group is set to *True*
RHS: *100* is assigned to **|NPO_WRFI|.importance** in
rule 48
NPO_WRFI.importance is set to *100*

SECTION C
Rejection of Discarded Subclasses

Rule 49 is set to false
NPO_WRFR is set to *False*
Rule 50 is set to false
PL_WIFI is set to *False*

. . . .
. . . .
. . . .

PW_WRFI is set to *False*
Rule 58 is set to false
PW_WRFR is set to *False*
Rule 37 is set to false

SECTION E
Level Three Rule

Condition there is evidence of **|NPO_WRFI|.group** in rule 3. (True).
Knot_Tails_Too_Long is set to *True*
Condition there is evidence of **Knot_Tails_Too_Long** in rule 3. (True).
Rule 3 is set to true
Bad_Knot.presence is set to *True*
RHS: **<|PointDefects|>.presence** is set to *FALSE* in rule 3
Bad_Knot.presence is set to *False*
Burnt_Holes.presence is set to *False*

. . . .
. . . .
. . . .

Neppy_Fabric.presence is set to *False*
Tear_Drop.presence is set to *False*
RHS: Show "causes/knots_long_tails"
@KEEP=TRUE;@WAIT=FALSE; in rule 3
Bad_Knot.presence is set to *True*

Figure 6.3b   Transcript of a Diagnostic Session for Bad Knots.

or Area, is used to classify the fabric defects at the first level with a rule such as Rule 54 in Figure 6.3a. Once the fabric defect *Type* is set to "Point", the value of *PointClassif* is set to true. To confine the search to the broad class of Point Defects and thereby speed up the system response, the Line and Area Defect classes are pruned by FDAS. As shown in Section B (Figure 6.3b), *LineDefects.presence, AreaDefects.presence, LineClassif.group* and *AreaClassif.group* are set to false; when this rule is fired, these values are automatically inherited by their subclasses. Section B of Figure 6.3b shows these steps. The role of the "*presence*" and "*group*" slots in the lower level rules will be explained in the following two sections; essentially, they eliminate the corresponding fabric defect classes from further consideration.

Level Two Rules. At this second level, FDAS further narrows the focus of search by using the other data volunteered by the user. The Level Two rule, Rule 48 in Figure 6.3a, uses the hypothesis of Rule 54 i.e., *PointClassif*, and the rest of the volunteered data about the *Direction* and *LengthwisePattern* and *WidthwisePattern* to prove *NPO_WRFI*. That is, this subclass is identified as one whose contents (individual fabric defects) all share that particular mode of occurrence, or set of visual characteristics. Once a particular defect's subclass is identified, further search is efficiently carried out in two steps:
1. FDAS focuses its search on only those defects belonging to the subclass established to be true -- *NPO_WRFI* in this case.
2. FDAS explicitly establishes that the defect described by the user does not belong to any of the other subclasses so that the inference process need not establish this from the volunteered data.

The *group* slot of a particular subclass is one of the data required to be true to establish the presence of any defect belonging to the subclass. Hence, the *group* slot is used to set evidence for whole classes of defects to be true or false. This is accomplished through actions 1 and 2 triggered by the firing of Level Two rules. The *importance* slot is used to direct the search to the set of rules leading to a particular class of defects. It is accomplished by the third action triggered by the firing of Level Two rules. The actions in this example are explained below (Refer to Rule 48 in Figure 6.3a and Section D in Figure 6.3b).

Action 1. *NPO_WRFI.group* is set to true.
Action 2. *PointClassif.group* is set to false. This value is inherited by all the other subclasses of PointClassif such as *CL_WCFI* or *CL_WRFR*, with the exception of *NPO_WRFI* whose *group* value has been explicitly set to true by action 1. Note that the Level One Rule 54 had already set *LineClassif.group* and *AreaClassif.group* to false, thereby setting the *group* slots of all their subclasses to false, using inheritance.
Action 3. In Nexpert Object, one method of explicitly changing the priority of a rule during an inference process is to use "category numbers." Rules with hypotheses having higher category numbers are considered first, and the category numbers can be reset dynamically. The *importance* slot of any class is used as the dynamic inference category number of each of the defects which are instances of that particular class. In this case *NPO_WRFI.importance* is raised to 100 from the default value of 1 (Section D in Figure 6.3b). Hence the search is explicitly focused on the subclass of defects which matches the user description. This part is shown in Section D of Figure 6.3b. The values of other defect subclasses such as *CL_WCFI, CL_WReFI*, etc., are set to false, in their alphabetical order, as shown in section C of Figure 6.3b.

<u>Level Three Rules.</u> The default inference mechanism of Nexpert Object imposed two major restrictions on the design of the Level Three rules. The working of the inference mechanism could not be altered to overcome these restrictions.

By the default mechanism (backward chaining), if a particular hypothesis is proven to be false by one rule, Nexpert Object directs the search to other rules leading to the same hypothesis. For example, if Bad_Knots is not proven by Rule 3, where it is considered to be an instance of the subclass *NPO_WRFI*, the system will still try to prove it as an instance of *NPO_WIFI*, which is already known to be false. Since each defect is an instance of four subclasses on an average, and since some defects can occur as an area defect and a line defect (*e.g.*, thin yarn, blend variation in yarn), such redundant searching will increase the time required for inferencing. To avoid redundant backward searching, rules of Level Two must be linked to rules of Level Three only in the forward direction. This can be achieved if the data required for Level Three Rules are not the principal hypotheses of the Level Two Rules, but are changed by the actions caused by the firing of Level Two Rules. Such one-way linking between rules is called a "weak link" in Nexpert Object. Since FDAS is expected to be used mainly for identifying the defect from a description of visual attributes, i.e., in data driven mode, and since it is necessary to minimize the inference time, it was decided to introduce weak links between Level Two and Level Three rules.

Rule 3, a Level Three Rule for the defect hypothesis Bad_Knots, does not use the principal hypothesis (i.e., *NPO_WRFI*) of the second stage rule, as its datum. Instead, it uses *NPO_WRFI.-group* as a datum, which was set to true by an action triggered by firing the second-stage Rule 48. Any change in the value of *NPO_WRFI.group* directs the inference to all the rules with *NPO_W-RFI.group* as one of their data, such as Rule 3. They are not linked in the backward direction because Rule 3 and Rule 48 do not share any data or hypotheses. Such "only forward" or "weak" linking between rules of Levels Two and Three helps avoid redundant search.

FDAS seeks information from the user about the Direction, and Lengthwise and Widthwise Patterns of the defect by presenting a menu with all the possible descriptions of each of these attributes. Since these attributes have only a limited number of descriptions to be considered, they can be displayed in a single menu. However, in the case of Appearance of the defect, FDAS presents the descriptions one by one, until the user confirms one of them. This is because Appearance has a unique description for each defect.

After pruning classes of defects based on the description of the other attributes, one would expect FDAS to question the user only about the Appearance of the defects, which have not yet been rejected. However, the menu presented by Nexpert Object, by its default functioning, contains all possible Appearance descriptions, including those corresponding to the already rejected defects. Since it is impossible for the user to go through a menu of approximately 85 items and make a selection, the user is presented with the Appearance descriptions one by one. It is achieved by having each Appearance description as a boolean variable, in contrast to Direction and Lengthwise and Widthwise patterns, which take strings for their values.

Once the user confirms a particular Appearance description, FDAS establishes the presence of the corresponding defect. The inference process must not attempt to establish the presence of other defects after confirming the presence of one. To prevent such redundant search, the presence

of every other defect has to be explicitly set to false. Consider Section E of Figure 6.3b in which the user confirms the defect appearance to be "Knot_Tails_Too_Long". This, along with the other already established datum -- *NPO_WRFI.group* -- confirms the defect described by the user as *Bad_Knots*. This is established in FDAS by setting *Bad_Knots.presence* as true. To prevent FDAS from trying to establish the presence of other Point Defects, *PointDefects.presence* is set to false. This slot is inherited by all the Point Defects with the exception of *Bad_Knots*, and hence explicitly set to false, in Rule 3, Figure 6.3a. At the very first level, Rule 54 had already set all Line and Area Defects to false by setting *LineDefects.presence* and *AreaDefects.presence* to false. This scheme prevents FDAS from considering other defects after confirming any single defect.

The primary consequence (as far as the user is concerned) of confirming the presence of Bad_Knots, is the display of a text file showing the conclusion of the system about the defect's identity, and a list of plausible causes and suggested remedies. This is done using the "Show" command in Rule 3 of Figure 6.3b. The text window can be kept displayed as long as the user wants. The working of the Level Three rule is shown in Section E of Figure 6.3b.

Additional Classification: Since Bad_Knots belongs to a subclass of defects with only six defects in it (see *NPO_WRFI* in Figure 6.2b), it is easy to reach a conclusion regarding the identity of the defect without further classification. On the other hand, a subclass such as *AreaNPO_WIFR* has 19 defects in it as shown earlier in Figure 5.3. These 19 defects have been categorized into four intermediate sub-categories based on commonalities of their appearance:
1. Stains/Shade Variation
2. Holes/Torn Fabric
3. Knots/Stretched Warp Yarns
4. Others

The implementation of this additional sub-categorization as an additional condition in Level Three rule is shown in Figure 6.4a (Area Defect), and its working is shown in section E of Figure 6.4b. Such sub-categories are very useful for speeding up the search for the current defect. Instead of the user being asked to select from among 16 individual defect Appearance descriptors, it is faster (in the average case) to select one of the four sub-categories and then be presented with a much smaller set of Appearance descriptors for matching.

6.3 User Interface

A well-designed computer system should encourage the user to explore all possible ways of using the system in performing the task better. One of the main barriers to achieving this goal is the anxiety of the users about making mistakes, and a general apprehension about anything new. User-friendly interfaces can go a long way in dispelling the anxiety of the user as quickly as possible, and in providing guidance in every aspect of interaction with the system. A good interface will not only minimize the possibility of user errors, but also be more tolerant towards the errors and boost the confidence level of the user. The strengths and weaknesses of the current DOS version of FDAS' user interface (UI) are discussed along with ways of overcoming the drawbacks.

LEVEL 1 : Rule 232
If **FabDefects.Type** is *"Area"*
Then **AreaClassif** is confirmed.
And **|PointDefects|.presence** is set to *FALSE*
And **PointClassif.group** is set to *FALSE*
And **|LineDefects|.presence** is set to *FALSE*
And **LineClassif.group** is set to *FALSE*

LEVEL 2 : Rule 247
If there is evidence of **|AreaClassif|**
And **|AreaDefects|.Direction** is *"No Particular Orientation"*
And **|AreaDefects|.LengthwisePattern** is *"Isolated"*
And **|AreaDefects|.WidthwisePattern** is *"Random"*
Then **AreaNPO_WIFR** is confirmed.
And **|AreaClassif|.group** is set to *FALSE*
And **|AreaNPO_WIFR|.group** is set to *TRUE*
And 100 is assigned to **|AreaNPO_WIFR|.importance**

LEVEL 3 : Rule 331
If there is evidence of **|AreaNPO_WIFR|.group**
And **|AreaNPO_WIFR|.SubGroup** is *"Stains/Shade Variation"*
And there is evidence of *Ill_Defined_Areas_of_Different_Shade*
Then **Shade_Variations_in_Fabric_Dyeing.presence** is confirmed.
And **<|AreaDefects|>.presence** is set to FALSE
And Show "causes/color_var" @KEEP=TRUE;@WAIT=FALSE;

Figure 6.4a   Three Levels of Rules for Shade Variation in
Fabric Dyeing - a Typical Area Defect

SECTION A

FabDefects.Type is set to *Area*
AreaDefects.Direction is set to *No Particular Orientation*
AreaDefects.LengthwisePattern is set to *Isolated*
AreaDefects.WidthwisePattern is set to *Random*

SECTION B

Condition **FabDefects.Type** is *"Area"* in rule 232. (True).
Rule 232 is set to true
AreaClassif is set to True
RHS: **|PointDefects|.presence** is set to FALSE in rule 232
PointDefects.presence is set to False
RHS: **PointClassif.group** is set to FALSE in rule 232
PointClassif.group is set to False
RHS: **|LineDefects|.presence** is set to FALSE in rule 232
LineDefects.presence is set to False
RHS: **LineClassif.group** is set to FALSE in rule 232
LineClassif.group is set to False

SECTION C

Rule 225 is set to false
AreaCL_WCFC is set to False
Rule 226 is set to false
AreaCL_WCFI is set to False
Rule 245 is set to false
....
....
....

AreaNPO_WReFR is set to False
Rule 246 is set to false
AreaNPO_WRFC is set to False

SECTION D

Condition there is evidence of **|AreaClassif|** in rule 247. (True).
Condition **|AreaDefects|.Direction** is *"No Particular Orientation"*
in rule 247. (True).
Condition **|AreaDefects|.LengthwisePattern** is *"Isolated"* in
rule 247. (True).

Continued...

Condition **|AreaDefects|.WidthwisePattern** is *"Random"* in rule 247.
(True).
Rule 247 is set to true
AreaNPO_WIFR is set to True
RHS: **|AreaClassif|.group** is set to FALSE in rule 247
AreaClassif.group is set to False
RHS: **|AreaNPO_WIFR|.group** is set to TRUE in rule 247
AreaNPO_WIFR.group is set to True
RHS: 100 is assigned to **|AreaNPO_WIFR|.importance** in rule 247
AreaNPO_WIFR.importance is set to 100

SECTION C

Rule 248 is set to false
AreaNPO_WRFR is set to False
Rule 249 is set to false
AreaPL_WIFC is set to False
....
....
....

Rule 253 is set to false
AreaPL_WRFI is set to False
Rule 254 is set to false
AreaPW_WIFI is set to False

SECTION E

Condition there is evidence of **|AreaNPO_WIFR|.group** in rule 258.
(True).
AreaNPO_WIFR.SubGroup is set to *Stains/Shade Variation*
Condition **|AreaNPO_WIFR|.SubGroup** is *"Stains/Shade Variation"* in
rule 258. (True).
Discoloration_or_Foreign_Matter is set to False
Condition there is evidence of *Discoloration_or_Foreign_Matter* in
rule 258. (False).
Rule 258 is set to false
Beam_or_Fabric_Contamination.presence is set to False
....
....
....

Condition there is evidence of **|AreaNPO_WIFR|.group** in rule 331.
(True).

Continued...

```
Condition |AreaNPO_WIFR|.SubGroup is "Stains/Shade Variation" in
rule 331. (True).
Ill_Defined_Areas_of_Different_Shade is set to True
Condition there is evidence of Ill_Defined_Areas_of_Different_-
Shade in rule 331. (True).
Rule 331 is set to true
Shade_Variations_in_Fabric_Dyeing.presence is set to True
RHS: <|AreaDefects|>.presence is set to FALSE in rule 331
Abrasion_from_Fabric_Mishandling.presence is set to False
Apron_Marks.presence is set to False
Bowed_Filling.presence is set to False
.............................................
.............................................
.............................................

Variable_Selvedge_Dyeing.presence is set to False
Wavy_Fabric.presence is set to False
Wavy_Selvedge.presence is set to False
Wrong_Pattern.presence is set to False
RHS: Show "causes/color_var" @KEEP=TRUE;@WAIT=FALSE; in rule 331
Shade_Variations_in_Fabric_Dyeing.presence is set to True
```

Figure 6.4b   Transcript of the Session for Shade Variation from Fabric Dyeing

<u>Interaction Style and Medium:</u>   The users of the system, i.e., personnel responsible for fabric inspection, are unlikely to be good typists. The same defect can be described differently by different users. Hence, using natural language description or command language for user interaction with the system is difficult. Since menu selection has several advantages, it has been chosen as the main mode of user interaction with the system. It does not require the user to commit anything to memory and needs minimum learning. Using menus greatly minimizes keystrokes. The user is presented with data in a structured way for decision-making. On the other hand, going through many menus one after another is a slow process even with a rapid display rate. One way of overcoming this disadvantage is by displaying all the menus together, and allowing the user to make one selection from each menu. The menu displays of FDAS are very clearly laid out and involve only simple selections.

<u>Semantic Organization of Menus:</u>   The UI menus in the system have been hierarchically decomposed, following the meaningful categorization of the underlying defects classification scheme. For example, the menus for selecting the extent and direction of defects are displayed in the following order: Partially Along the Length, Continuously Along the Length, Partially Across the Width, Continuously Across Width and No Preferred Orientation.

<u>Reversal of Actions:</u>   The menus for seeking data have been organized in such a way that there is no overlap in the information sought in any two menus. This should reduce the need for the user to change the response to any of the earlier queries at a later stage. But, knowing that the actions taken at any stage are reversible will certainly alleviate the user's anxiety about committing errors. The current DOS version of FDAS allows the user to change any of the already volunteered data at any point during a diagnosis session. But if the user changes his/h· r mind at a late point in a session, he/she may be required to go through three levels of menus or restart the session from the beginning. In future versions of the system, all the menus should be displayed in a table throughout the session with the user-volunteered data highlighted. It should be possible for the user to change the volunteered data just by clicking on some other choice in the menu with the mouse. Not having to remember the responses to earlier queries will also reduce the cognitive load on the user.

<u>Reduction of Short-Term Memory Load:</u>   The number of choices to be considered in a menu ranges from three for Fabric Defect Type to five for the Defect Direction. This is well within the limitation of human-information processing in short-term memory, as many studies [Mill 81, Kige 84] have established that menus with up to eight items maximize user speed and minimize error rate.   The "depth of interaction" i.e., the number of menus that a user has to go through is as important as the "width of each interaction" or the number of items in each menu.   With FDAS, the user has to go through five levels of menus if the subclass has eight or fewer defects, and six levels if there are more defects in the subclass (because of the additional intermediate sub-categorization; please see Section 6.2).

<u>Output Organization:</u>   All the output from FDAS is in the form of text in separate pop-up windows. The user interface shown in Figure 6.1 is distinct from the full-blown graphical interface for developers using Nexpert Object. The default output is the final diagnosis, comprising the name of the defect just identified, its probable causes and suggested remedies. The location as well as display duration of this pop-up window display are completely under the control of the user. Other output screens or menus are dispalyed if the user makes an error, or if there is an intermediate sub-

categorization in the sub-class described by the visual defect characteristics.

Response Time: Since the system is to be used by the fabric inspector on the shopfloor, it is extremely important that the system responses be as fast as possible. If the system takes too long to respond, it will not only cause loss of production, but will also lead to impatience on the part of the user, and ultimately to disuse of the system itself. FDAS' response is almost instantaneous for displaying the series of menus which enable user input of the defect's visual characteristics. Most diagnosis sessions take 5-7 seconds after user input has been completed to display the analysis and recommendations. Even where a further level of menus is necessary, actual system working time is still about 10 seconds, and only about 30% of overall session elapsed time. This is because most of the session elapsed time is a function of the time the user takes to indicate menu selections, read defect descriptions, etc. Most diagnosis sessions take between 10-20 seconds.

Error Handling:The chances for user error have been minimized by using menu selection as the predominant style of user interaction. Only in two cases, FDAS may not be able to reach a conclusion based on the information supplied by the user. In one instance, the user supplies a description of a defect as a set of characteristics which are physically impossible or self-contradictory. In the other, the user may not have accepted any of the defect appearance descriptors as matching what is actually seen on the fabric. In both the cases, FDAS displays an error message prompting the user to redescribe the defect.

CHAPTER 7

SEWING DEFECTS: KNOWLEDGE ACQUISITION

The first step in the development of a sewing defects analysis system is to acquire and organize information on sewing defects, their causes and remedies. This chapter presents a detailed account of the tasks carried out to accomplish this objective.

Another aim during this phase of the research has been to define the specifications of the software system more accurately. Factors considered in this process were possible applications, user profiles, further extensibility and response time requirements.

7.1 Garment Defects: Sources of Knowledge

The bulk of the literature reviewed concerning sewing and assembly defects were books and Federal/military specifications. Useful information was also derived from a series of interviews with technical experts at academic institutions and apparel plants. The garment inspection process, and the procedures used for sampling and re-work of defectives were carefully studied at a number of apparel plants.

Military and Federal specifications provided details of the construction of utility trousers and the quality inspection procedures used in manufacturing. One of the specifications dealt exclusively with garment defects and their varied levels of seriousness. Some of the specifications provided effective guidelines for identifying defect-prone tasks and processes, and for studying garment assembly, machines and inspection procedures during plant visits.

MIL-STD-87062A is the military specification which lays out material requirements and assembly sequences to be used by an apparel contractor to manufacture denim utility trousers to meet service requirements. It also refers to other official documents for the design, manufacture and quality inspection of all constituents such as fabric, buttons, zippers, sewing thread, and packing material. All the processes in the manufacture of a utility trouser, from the cutting to final garment inspection and packaging are described in detail.

MIL-STD-1488F is another specification used by the military to provide guidelines for inspectors checking the quality of various types of trousers (including utility denim). Garment defects are classified into *critical, major* and *minor* types; they are also sub-divided into categories based on their type and location on the trouser. Details of sampling schemes per production lot are supplied. Every defect description is accompanied by a penalty point assignment; the cumulative point accumulations define acceptance and rejection thresholds for each production lot at different levels of inspection.

Other Standards and specifications provide details on the various types of seams and stitches used (Federal Standard #751), and on the required structure and performance of the fabric used to produce the garment (e.g., MIL-C-24915 for fire-retardant cotton denim). The Federal Specifi-

cations V-B-871, V-F-106, and V-T-280 are publications dealing with the construction and performance of buttons, slide fasteners and cotton buttonhole thread, respectively. A large amount of detail is also available on recommended procedures for statistical sampling for quality evaluation and identification measures for storage and shipment. All these documents provide very important guidelines for characterizing the garment defects domain. Several aspects of the specifications, e.g., the construction sequences laid down in MIL-STD-87062A, have influenced the structure of the software.

Several textbooks served as sources of information on current apparel manufacturing practices, machinery and processes, cutting and sewing sequences for different types of garments and inspection norms. These books also provided an overall picture of the impact of classification and analysis of defects in the sewing room on the percentage of first quality production, operator assessment, machine monitoring and production planning. Typical of these are the "Apparel Manufacturing Handbook" by Solinger [Soli 80], "Guide to Apparel Manufacturing" by Peyton Hudson [Huds 88], the "Quality Control Handbook" by J. M. Juran [Jura 74], and "An Introduction to Quality Control for the Apparel Industry" by Pradip Mehta [Meht 85].

Several research papers gave deeper insight into some facets of the domain of apparel manufacturing including defects. Some of these pertained to the quality of fabric and trim elements, and others treated quality maintenance within the various operations such as cutting and sewing. Other papers and technical reports presented research into specific types of defects such as seam pucker, and the various organizational aspects and importance of quality control methods and procedures.

Perhaps the most important source of information was the technical consultations and discussions relating to the economic and technical aspects of apparel defects with experts at AMTC. These discussions initially attempted to enumerate different types of defects arising in a trouser manufacturing operation, and to describe them in the most efficient yet comprehensive way. The focus then shifted to assessing the potential of each assembly process to generate each of the enumerated types of apparel defects. This process resulted in a complete map of causal relationships between every kind of manufacturing parameter at every stage of assembly and possible defects which could be generated in the product. The experts also assisted in identifying the remedies for different defects.

Using procedures similar to that for FDAS, the domain was analyzed, followed by the development of a defects classification scheme. For SDAS, the classification centered around two primary decision criteria: the **location of the defect**, and the **nature of the defect**. These classification criteria were found to be adequate for describing each defect uniquely and for advising on that defect's causal factors and prescription of remedies. It was decided to incorporate the utility trouser construction specifications (MIL-STD-87062A) in the SDAS software; using this, SDAS would be able to render relevant advice regarding construction standards for the operation that is judged to be responsible for a particular defect.

7.2 Classification Scheme

The defects classification scheme is structured around two main criteria: the location of the defect, and the nature of the defect. These are the two major visual cues that an inspector derives from the garment being inspected. This two-component input from the inspector immediately points the system software in the right direction. The software would then have to precisely determine the manufacturing stage or assembly process that caused this defect, questioning the user further if necessary. Once the manufacturing operation is identified, the software can suggest probable causes and remedies.

The "Nature of Fault" descriptor is further split into several subclasses as shown in Figure 7.1. These subclasses are further classified whereever necessary. Other subclasses can also be classified as needed. For instance, the subclass *Appearance* has not been classified further since most items in this subclass stem from fabric defects, which is a domain covered by FDAS.

Most defects in the *Position/Alignment/Incorrect Component* category have been subsumed into the *Seam Formation, Stitch Formation* or *Others* categories. Also, in Figure 7.1, Raw Edge defect, because it is not clearly assignable to either of the Seam Formation or Stitch Formation categories, is listed under both the categories.

Figure 7.2 illustrates the "Defect Location" classification hierarchy. Since the military utility trouser has a very simple construction with fewer parts compared to most other garments, the class hierarchy is also simple.

There is another set of classes which comprises the "Specification" set. This is a hierarchy of classes containing the entire MIL-STD-87062A specification dealing with operational parameters and processes. These organize the garment construction data available in the specification document, so that the relevant specifications can be referred to for recommendations pertaining to the operation deemed responsible for the defect being examined by the user.

7.3 Defect Occurrences and Causal Factors

As in the case of FDAS, the model chosen here is of the associational type. The reason for preferring this over a detailed causal model are the difficulties associated with fully understanding and representing all the relationships between entities in an exhaustive way. In the domain of garment manufacturing defects, diagnostic information is predominantly heuristic. However, there are some cause-effect relations which may be rigidly codified and generally applicable. (An example of this would be "cutter lean", which is a stacking defect at the cutting table which would cause all the parts within a certain bundle to have some of their dimensions progressively going out of tolerance).

A hybrid formal representation is chosen for representing the entities in this domain of sewing defects, comprising *class-object hierarchies* and *rules*. Since the entities in the domain knowledge were hierarchically classifiable, it was possible to represent them using classes and objects. The use of class hierarchies has several advantages such as making the knowledge in SDAS highly

NATURE OF FAULT

OMISSIONS

Part Omitted
Closure Omitted
Uncut Buttonhole
Pressing Omitted

OTHERS

DimensionsOutOfTolerance
Exposed Notches
Caught Place
Excessive Fullness **

STITCH FORMATION

Broken Thread
Insecure BackStitch
Wrong /Irregular Stitch Gauge
Loose/Tight Thread
Mislocated Reinforcement
Needle Chew
Open Seam
Raw Edge **
Skipped Stitch
Uneven Stitch Line
Wrong Thread

FIN / PRESS FOLD / PACK

Finishing
Pressing
Folding
Packing

POSITION / ALIGNMENT / INCORRECT COMPONENT

Misplaced Component
Component Size/Shape Not To Spec
Excessive Fullness **
Wrong Component

SEAM FORMATION

Raw Edge **
Misaligned Seam
Pleated Seam
Puckered Seam
Run Off
Twisted Seam

APPEARANCE

DEFECTIVE TRIM

Zippers
Slider Defects
Chain/Tooth Defect
Top/Bottom Stop
Tape/Cord Defects

Labels

Thread
Thread Color
Thread Quality

Buttons

CLEANLINESS

Finishing Streaks
Soiling
Spots & Stains
Hanging Thread
Sewn-In Waste

COLOR MATCHING

DEFECTIVE FABRIC

Thick Places
Slubs
Knots
Dyeing Streaks
. . . .

Figure 7.1 "Nature of Defect" Classification Hierarchy

structured, and in explicitly rendering the relationship between different entities within the knowledge base. However, the part of the rule base using entity descriptions for actual diagnosis inferencing, and those rules controlling this inferencing process are not as clearly distinguishable as in the structure of FDAS (the latter accomplishes its modularity by the use of two distinct class hierarchies).

As with FDAS, classes and objects represent categories of defects and individual defects and rules are used to identify defects based on user description.

There are currently 18 major types of sewing and assembly defects treated in SDAS, within the sub-categories Stitch Formation, Seam Formation and Other Defects. However, analogous to the different modes in which each one of the fabric defects can occur in FDAS, each of the assembly defects can arise at any stage in the manufacturing sequence. Depending on the origin, the cause may be any one of a variety of factors. Hence, the SDAS software relies on a scheme which combines two types of diagnosis information, *general* and *specific*. General diagnosis and correction measures are those which would hold and be correct irrespective of the operation which gave rise to a particular defect on the garment. On the other hand, most defects can have specific causal factors at individual operations within the garment assembly sequence, whether they are caused by operator, machine, or process parameters. SDAS has access to such specific diagnostic information.

Once the manufacturing operation responsible for the defect is determined, the general diagnosis for that defect and the relevant specific diagnosis are dynamically combined by SDAS in a context-sensitive manner and displayed to the user. As in the case of FDAS, the diagnosis information is stored in text files. They are thus very easy to modify and customize using any simple text editor. Even if an organization wishes to refine the diagnosis down to machine specifics, e.g., stitch gauge settings on a Brother® sewing machine, this can be accomplished easily.

7.4 Special Defects in Denim Trouser Assembly

There are some special considerations in any assembly process that uses cotton denim cloth of the usual weights. A typical characteristic of such cloth is its high stiffness and tightness of weave. While this renders a common problem such as seam pucker more easy to avoid, such dense and stiff fabric usually causes excessive thermal and abrasion stresses on a machine's moving parts, leading to greater wear and tear. Since the size of sewing thread is also bigger, there are likely to be large frictional effects in the needle zone.

Another problem in assembling utility trousers from cotton denim is the generation of relatively high proportions of lint and fly in the sewing room. One reason for this is the use of soft-twisted cotton yarn in the filling direction; another is the rubbing off of indigo-dye particles from the cloth due to friction with the fast-moving stitching components on the sewing machine. On the other hand, because of the all-cotton content of the garment components, there is little static attraction and clinging tendency. Therefore, each piece in a bundle is likely to maintain its shape and place and not be susceptible to folding on itself due to surface effects.

There are two major aspects of the construction of denim utility trousers that set them apart

DEFECT LOCATION

POCKET

Left Front Pocket
Left Back Pocket
Right Front Pocket
Right Back Pocket

FRONT
OPENING

Left Fly
Right Fly
Crotch-Seatseam Junction

MAIN
PANELS

Upper Left Front
Upper Left Back
Upper Right Front
Upper Right Back
Lower Left Front
Lower Left Back
Lower Right Front
Lower Right Back

BAND

BELT
LOOPS
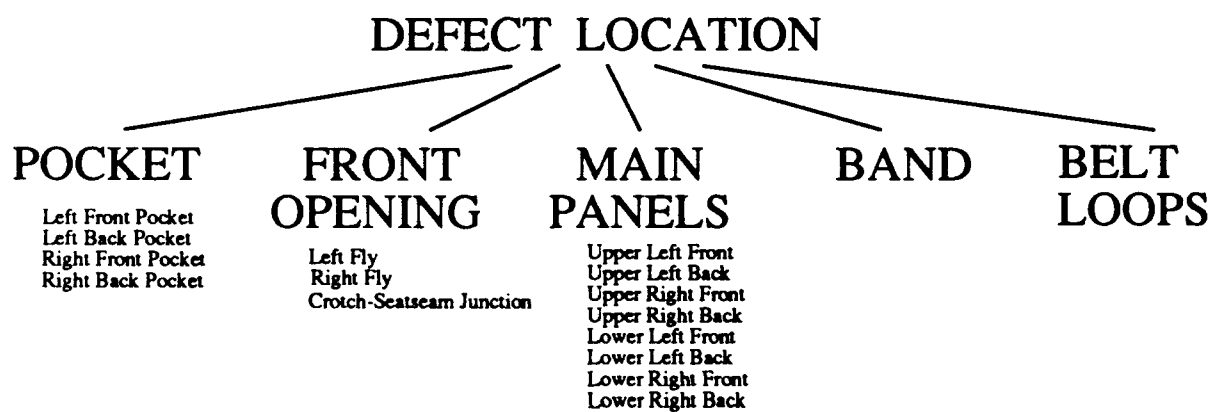
Figure 7.2 "Location of Defects" Classification Hierarchy

from the assembly of other garments. One is the very simple construction of this garment, which has fewer operations than most other trouser assembly sequences. Pocket design and attachment are very simple, and each belt loop has positioning clues on the garment which minimizes errors. This also contributes to reduced errors in pattern design, cutting, bundle mix-ups and faulty component positioning.

The second is the preponderance of double-felled double-lapped seams. This results in a larger percentage of certain sewing errors (such as needle chew when one seam runs across another and fabric thicknesses jump by over 100%) and less of others (such as a raw edge). This type of seam requires the machine folders to be in good condition. The construction of the waistband may also give rise to a rather uncommon set of errors in alignment of the main panels with the long edge of the waistband and alignment of the turned-in waistband corners.

CHAPTER 8

SEWING DEFECTS: REPRESENTATION AND REASONING

In this chapter, the conceptual design for the domain of garment defects, and the formal mapping of this conceptual model into software are discussed. A scheme for the visual identification of sewing defects is presented, along with a suitable defects classification scheme. Following this, the chosen modes of analysis and diagnosis using this representation scheme are discussed.

8.1 Partitioning the Set of Defects

As described in 7.2, the classification scheme is structured around two main criteria: the location of the defect and the nature of the defect. The hierarchy trees are expressed as class-object structures similar to those implemented in FDAS, for purposes of modularity, ease of testing and later modification. All major defect type classification entities (*Nature of Defect*) and their type groupings (e.g., *Seam Formation*) are classes, as seen in Figure 8.1a. Their contents are sub-classes representing individual types of defects, each of which is in itself a class comprising objects denoting the occurrence of that particular type of defect at each of the manufacturing operations in the assembly sequence. For example, the defect type sub-class *Twisted Seam* is one of the members of the class *Seam Formation*, and has as its children the objects *Twisted Seam at the Attach Belt Loops Operation, Twisted Seam at the Attach Waistband Operation, Twisted Seam at the Inseam Operation*, etc. In a similar fashion, the defect type sub-class *Open Seam* is developed into a whole list of member objects representing the defect at various manufacturing operations, as is the defect type sub-class *Raw Edge* and so on. This set of class-object structures also affords a measure of commonality for expressing defect analysis schemes for other garments in the future.

As seen in Figure 8.1b, there are also some *class property* slots. The most important are the slots *op_code* and *specific_operation*. Consider the class *Twisted Seam* shown and all its children objects; these slots are initialized with different data individually identifying each object. Hence, object *Twisted Seam at the Attach Belt Loops Operation* will contain the data "abl" in its slot *op_code* and the data "Attach_Belt_Loops" in its slot *specific_operation*. The object *Twisted Seam at the Attach Waistband Operation* will contain data "awb" in slot *op_code* and the data "Attach_Waistband" in the slot *specific_operation*. As will be seen in Section 9.1, these slots play an important part in the working of the diagnosis rules.

Similarly, the location where these defects appear on the garment is expressed in another class-object structure, as shown in Figure 8.2. It must be noted that this is where the current defects classification scheme departs from generality. This location classification is used for the most efficient and succinct description of the visually-distinct locations and sub-assemblies for denim utility trousers following the MIL-STD-87062A specification. This location classification tree will be different for the structures and assembly sequences of other garments, and the software will therefore have to be customized to deal with those.
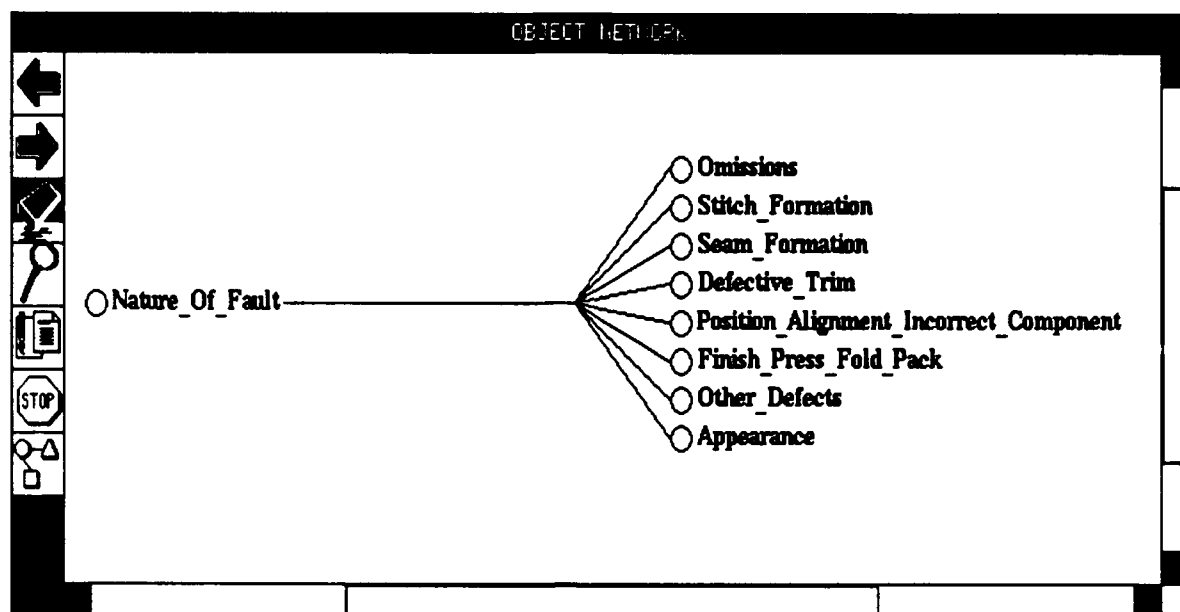
Figure 8.1a "Nature of Defect" Class Hierarchy, First Layer
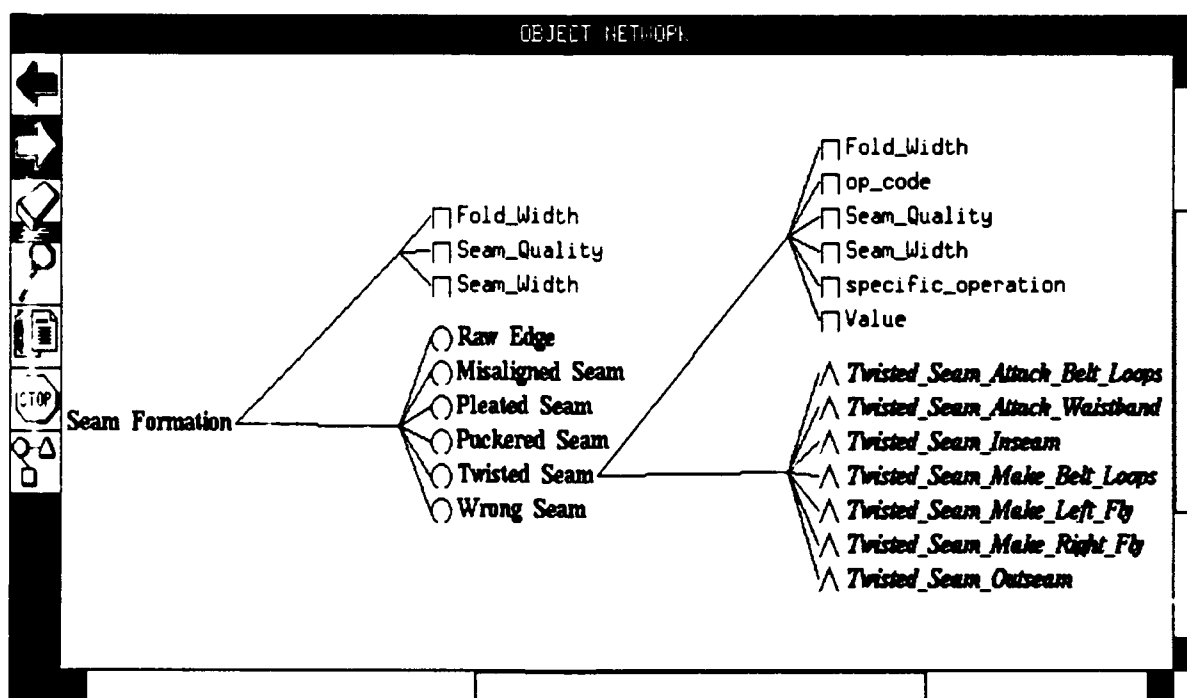
Figure 8.1b "Nature of Defect" Class Hierarchy, Second Layer, Sub-Class "Twisted Seam"
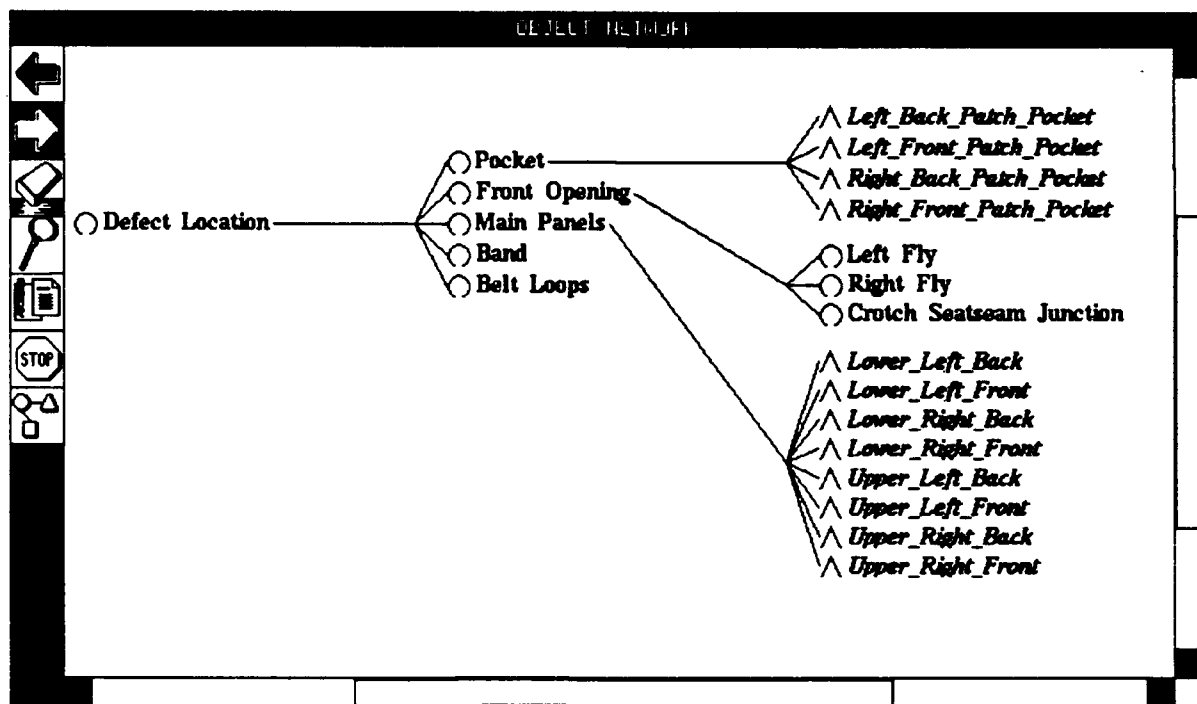
Figure 8.2   "Location of Defects" Class-Object Hierarchy
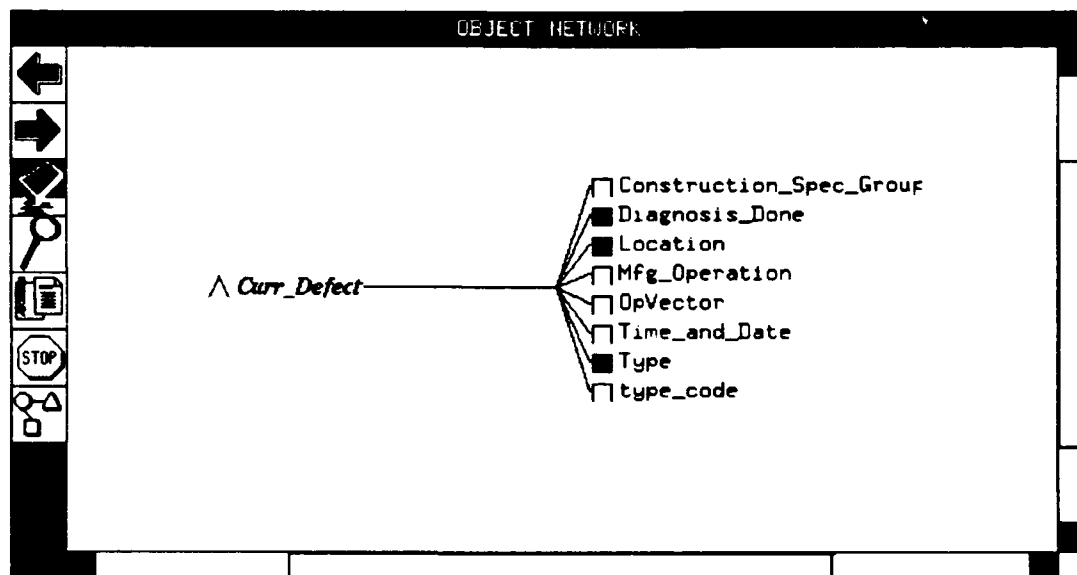
Figure 8.3   "Current_Defect" Representation Object

The *current_defect* object is used to collect data about the defect in each diagnosis session, starting out with the user-volunteered identification of defect type and location. As SDAS builds up a profile of the defect during the diagnostic session, more defect characteristics and defect-related information (derived from the inference process) are stored in the slots of this object *current_defect* (Figure 8.3). Filled squares in the property slot references mean that there are some initial modifications to these properties. These modifications may be used for specifying initial values, invoking demons for performing actions such as changing inheritance dynamically, or to override the Nexpert Object default query about any object ("what is the value of...") and supply in its place one which is more specific and meaningful.

Among the several slots used during the diagnosis session are Boolean slots to represent the status of the overall diagnosis process. The *Location* slot is used as a datum for the second level of rules, to ensure that the diagnosis has indeed proceeded to the point where the manufacturing operation has been deduced from the information supplied by the user regarding defect location on the garment. The *Diagnosis Done* Boolean slot is reset from false to true by other rules, once the defect has been analyzed and the diagnosis and recommendations have been displayed, SDAS can then transmit that session's defect data into a database, if necessary.

As soon as the user selects the location of the defect from the input menu, the response is assigned to the slot *Location*. The slot *Type* will contain the corresponding user response for the nature of the defect. The slot *Mfg_Operation* will be assigned the manufacturing operation responsible for the defect currently being observed. As soon as this likely source is identified, a group of relevant construction norms out of the MIL-STD-87062A document is identified; the name of this specification group is put into the slot *Construction_Spec_Group*.

As the diagnosis session proceeds, the user supplies a choice for the nature of the defect being seen in the garment; the analysis rules store an abbreviation representing this defect in the slot *type_code*. For example, if the user sees a bartack misplaced by a half-inch on the crotch junction and therefore chooses Mislocated Reinforcement as the type of defect, the contents of *type_code* will be the notation "mr". This notation will be modified and added to if there is diagnosis information specific to the Crotch Bartacking operation, which caused this defect.

8.2 Structuring the Diagnosis Knowledge

To permit easy reading and modification of the stored diagnosis files, the system uses a simple scheme of keeping generic and more specific information together in logically-related groups of scripts. Each group is isolated in one filesystem directory. As in the case of FDAS, text files contain all the diagnosis information, and are very easy to modify and customize using any text editor. Even if an organization wishes to refine the diagnosis down to machine specificities, e.g., folder settings on a Pfaff® double-stitch machine, or maintenance schedules for a group of machines, this can be achieved without much difficulty.

At present, SDAS contains diagnosis information for 18 types of sewing and assembly defects within the sub-categories Stitch Formation, Seam Formation and Other defects. Each of these assembly defects can arise at any stage in the manufacturing sequence. For each particular defect, there may be some common causal factors which may be independent of the manufacturing oper-

ation or stage in the assembly sequence. This type of "general diagnosis" information, which would be correct irrespective of the operation which gave rise to that particular defect or its location on the garment, is in a script named with the abbreviation representing the defect. Each of these generalized defect diagnosis scripts resides in a directory bearing the same name. For example, the defect type *Open Seam* has a generalized diagnosis script "os", residing in a directory "os". The defect type *Raw Edge* has a generalized diagnosis script "re", in a sister directory to "os" called "re".

Most defects can have specific causal factors at individual operations within the garment assembly sequence, whether they are caused by operator, machine, or process parameters. SDAS has access to such specific diagnostic information. These scripts are labelled in a systematic manner with each label comprising the abbreviation of the defect type first, and a subsequent two- or three-letter abbreviation representing an operation or stage within the manufacturing sequence. Within each directory named by the abbreviated form of the defect type, these specific scripts are also stored for as many operations as have such distinct diagnostic information pertaining to this particular defect type. For example, directory "os" will contain not only diagnostics for Open Seams in general (file "os"), but also specific recommendations for Open Seams at the Attach Belt Loops Operation (file "osabl"), at the Attach Label Operation (file "osal"), at the Attach Left Fly Operation (file "osalf"), at the Attach Patch Pockets Operation (file "osapp"), etc. The operation-specific scripts are in alphabetical order.

Once the assembly operation causing the defect is determined, the general diagnosis for that defect and the relevant specific diagnosis (if one is available) are dynamically combined by SDAS and displayed to the user. For operations which do not have specific diagnosis scripts for a particular defect, only the generalized script is displayed[1].

8.3 Representation of MIL-STD-87062A Utility Trouser Construction Specifications

While the construction specifications cannot provide any guidelines for the analysis and diagnosis of defects, they do provide the norms that govern the manufacturing procedures and tolerances at each step in the assembly process. Since the specifications are not likely to change during the operational life of SDAS, it is preferable to incorporate the entire specifications into the Nexpert Object software framework.

As with any Nexpert Object static representation in FDAS or SDAS, the construction specification is expressed as classes and objects. The overall specification groupings of assembly operations are expressed as classes and objects. The topmost level of this hierarchy of classes, shown in Figure 8.4, depicts the various specification groupings corresponding to the assembly operations in the manufacturing sequence(s) laid down by the military procurement authorities for denim utility trousers.

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1. This system of abbreviations for the file names and their manipulation (described later) has been adopted to ensure the working of the SDAS on MS-DOS machines. MS-DOS naming restrictions do not permit file names such as "Open_Seams" or "Open_Seams_at_Operation_Patch_Pocket", which would have been more intuitive.

OBJECT NETWORK

□ Allowed_Tolerance
□ Norm_Description
□ Seam_Type
□ Spec_Operation_Class
□ Spec_Value
□ Stitch_Type
□ Stitches_Per_Inch_Spec

○ SpecClass_Attach_Belt_Loops
○ SpecClass_Attach_Label
○ SpecClass_Attach_Patch_Pockets
○ SpecClass_Attach_Waistband
○ SpecClass_Bartack
○ SpecClass_Button
○ SpecClass_Buttonhole
○ SpecClass_Join_Outseams_And_Inseams
○ SpecClass_Make_Belt_Loops
○ SpecClass_Make_Darts
○ SpecClass_Make_Patch_Pockets
○ SpecClass_Attach_Left_Fly_To_Left_Front
○ SpecClass_Attach_Right_Fly_To_Right_Front
○ SpecClass_Attach_Waistband_Left_End
○ SpecClass_Attach_Waistband_Right_End
○ SpecClass_Attach_Waistband_Jstitch
○ SpecClass_Join_Crotch_Seam
○ SpecClass_Join_Seat_Seam
○ SpecClass_Make_Left_Fly
○ SpecClass_Make_Right_Fly

○ Construction_Norm_87062

Figure 8.4   Construction Specification Class-Object Hierarchy, First Level

At the top of Figure 8.5, the class properties are shown. These correspond to the headings seen in the paper document, and are all of the type string. For example, the slot *norm_description* contains the description of some type of operational advice or requirement, and the slot *stitch_type* contains a reference to the formation of the seam recommended (with a set of abbreviated descriptors referenced from Federal Standard #751 for seams and stitches) for this operation. The slots contain references to each of the fields in an element within the specification groups, and the overall class structure reflects the operational sequence normally recommended for the manufacture of utility trousers.

Within each heading in the paper document, i.e., within each class in the "Construction Specification MIL 87062," there are a number of objects representing the logically-connected set of specifications within that heading. Since the heading normally comprises several individual specification items in the set, each class will consist of one or more objects. Figure 8 shows the expansion of one of the specification classes, namely, *Join Crotch Seam.* There are two separate specification items in this class, each represented as an object with its slots fully representing all the paper document's norms and recommendations.

During a diagnosis session, the class hierarchy relevant to the defect being observed is available for instantaneous look-up. When SDAS has received the set of visual features regarding the defect, and has arrived at the manufacturing operation most likely to have caused the defect, the group of specifications pertaining to this operation is marked as useful. There is also a way to remove some of these specifications from this selected group, depending on the operational relevance in a particular manufacturing set-up. For instance, an organization may follow a small variation of the manufacturing sequence, or it may have a completely modernized set of machinery in the sewing room. In that case, some of the norms and requirements are of little value. These can be disabled by setting the slot *Operationally Relevant Spec* to a Boolean value of False. Such settings are to be made when customizing SDAS prior to its use in the plant.
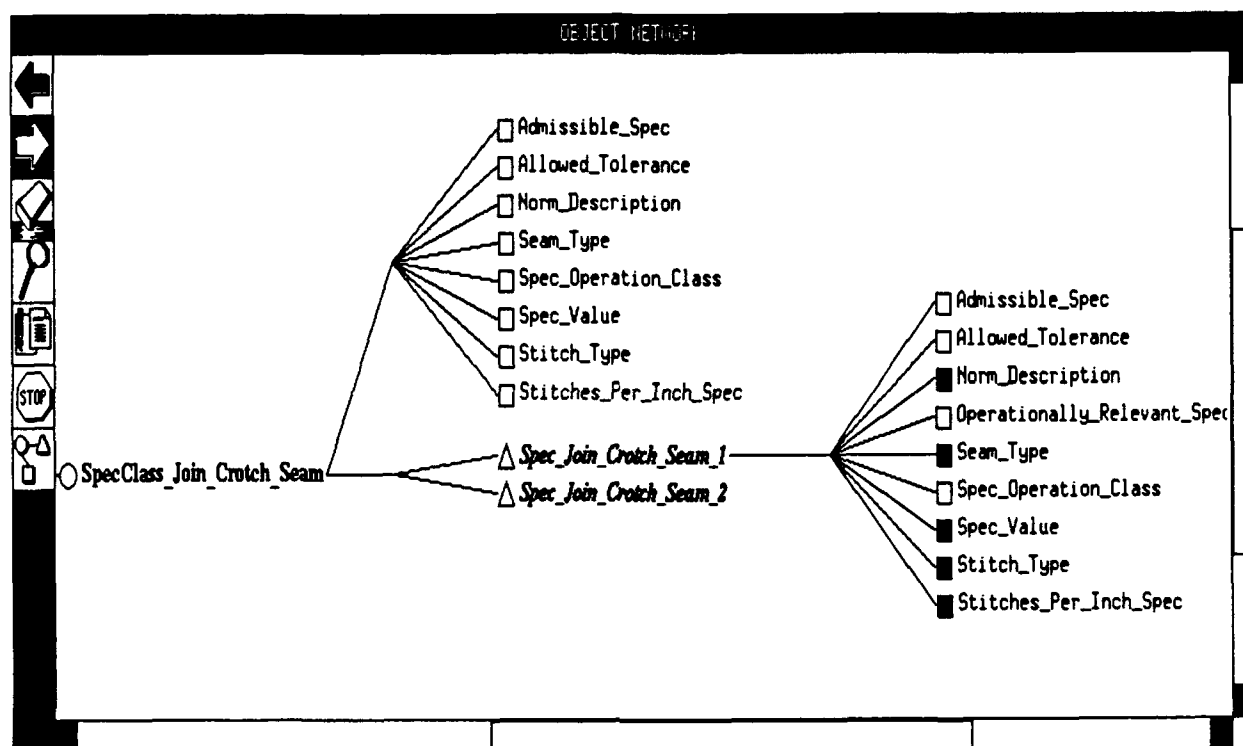
Figure 8.5   Construction Specification Class-Object Hierarchy, Second Level

CHAPTER 9

SEWING DEFECTS: SOFTWARE IMPLEMENTATION OF THE ANALYSIS FRAMEWORK

This chapter covers the details of the software development of SDAS, and discusses the arrangement of the reasoning processes to carry out the classification/diagnosis task. In SDAS, domain knowledge is represented using a hierarchy of classes and objects, and reasoning is implemented using rules.

The software implementation is explained and illustrated with two test cases. The first is a simple case of a skipped stitch somewhere along the length of the waistband which will illustrate the fundamental layout of the reasoning mechanism using rules working over the static class-object hierarchy. A detailed transcript of the inference process is provided, showing how a diagnosis is made. The user has also chosen to scan the corresponding sections of the specification document. The second is a more complicated case of an open seam on a belt loop. This example describes the dynamic combination of a generalized set of recommendations with a particular set of specific recommendations for the culprit operation identified by the system. In the second case, the user has not requested to view the relevant construction specifications.

9.1 Working Principles: Analysis and Diagnosis

Nexpert Object has been used for the implementation of SDAS. Separate cass hierarchies are used for expressing the criteria *Nature of Defect* and *Location of Defect*. Atoms such as *Location_Found* and slots such as *Diagnosis_Done* of the atom *Curr_Defect* are used to flag the status of the defect diagnosis session, and trigger the use of different sets of reasoning rules. The majority of reasoning rules are arranged into two tiers or sets, similar to the arrangement in FDAS. Each set of rules forms a group of associative pattern matchers; one set is keyed upon the "Location of Defect" criterion, and the second on the "Nature of Defect" criterion. The second level of rules consists of matched pairs of rules, one pair for each major type of defect (see Figure 9.1a).

The hypothesis for each pair is the same, but their priorities of action are different. The Level 2(b) rule in Figure 9.1a shows a rule for the defect "Skipped Stitch" which uses a default priority of 1. This rule would only display a generalized diagnosis file for this defect, if it were to operate. The Level 2(a) rule is a more specific rule, with a higher priority of -100. It is an attempt to determine a more detailed profile of the current skipped stitch defect, so that a more specific diagnosis can be made to supplement the generalized one.

The slot *Curr_Defect.Location* is first volunteered. The slot *Curr_Defect.Type* is volunteered second. Let us assume that the user sees a Skipped Stitch on the Waistband of the garment, as in Section A of Figure 9.1b.

Level One Rules: The Level One rules now attempt a pattern match on the data given for the Location of the defect. A series of defect location hypotheses is dismissed, as seen in Section B of Figure 9.1b. Then in Section C, a match is found for the second datum in the Level One rule

```
LEVEL 1 :   Rule ObservedDef_Waistband
If there is no evidence of Location_Found
And Curr_Defect.Location is "Waistband"
And there is evidence of a Waistband_RightEnd
    Then Attach_Waistband is confirmed.
And |Curr_Defect|.Mfg_Operation is set to "Attach_Waistband"
And <|SpecClass_Attach_Waistband|>.Admissible_Spec is set to TRU
And Spec_Attach_Waistband_And_Size_Label_5.Admissible_Spec
is set to FALSE
And Location_Found is set to TRUE
```

```
LEVEL 2 (a):   Rule Skipped_Stitch_Def_In_Specific_Operation;
            PRI= -100;
If Curr_Defect.Type is "Skipped_Stitch"
And there is no evidence of Curr_Defect.Diagnosis_Done
And <|Skipped_Stitch|>.specific_operation matches
Curr_Defect.Mfg_Operation
    Then Skipped_Stitch is confirmed.
And |Curr_Defect|.type_code is set to "ss"
And |Curr_Defect|.OpVector is set to
STRCAT(Curr_Defect.type_code, <|Skipped_Stitch|>.op_code)
And "concat" is Executed
And "tempfile" is Shown (@KEEP=TRUE,@WAIT=FALSE)
And Curr_Defect.Diagnosis_Done is set to TRUE
```

```
LEVEL 2 (b):   Rule Skipped_Stitch_Defect
If Curr_Defect.Type is "Skipped_Stitch"
there is no evidence of Curr_Defect.Diagnosis_Done
    Then Skipped_Stitch is confirmed.
And "causes/ss/ss" is Shown (@KEEP=TRUE,@WAIT=FALSE)
And Curr_Defect.Diagnosis_Done is set to TRUE
```

Figure 9.1a   Two Levels of Rules: Skipped Stitch Defect, on the Waistband

SECTION A
Filling Slots with User Volunteered Data

Curr_Defect.Location is set to *Waistband*
Curr_Defect.Type is set to *Skipped_Stitch*

SECTION B
Rejection of Defect Locations

Rule 36 is set to false
Rule 35 is set to false
Make_Right_Fly is set to *False*
Rule 34 is set to false
Rule 33 is set to false
Make_Patch_Pockets is set to *False*
. . . .
. . . .
Rule 24 is set to false
Join_Crotch_Seam is set to *False*
Rule 13 is set to false
Rule 10 is set to false
Bartack is set to *False*

SECTION C
Level One Rule

Condition there is no evidence of **Location_Found** in rule
ObservedDef_Waistband_Right_End (True).
Condition **Curr_Defect.Location** is "*Waistband*" in rule
ObservedDef_Waistband_Right_End (True).
Waistband_RightEnd is set to *False*
Condition there is evidence of **Waistband_RightEnd** in rule
ObservedDef_Waistband_Right_End (False).
Rule 9 is set to false
Attach_Waistband_Right_End is set to *False*
Condition there is no evidence of **Location_Found** in rule
ObservedDef_Waistband_Left_End (True).
Condition **Curr_Defect.Location** is "*Waistband*" in rule
ObservedDef_Waistband_Left_End (True).
Waistband_LeftEnd is set to *False*
Condition there is evidence of **Waistband_LeftEnd** in rule
ObservedDef_Waistband_Left_End (False).
Rule 8 is set to false
Attach_Waistband_Left_End is set to *False*

Continued...

Condition there is no evidence of **Location_Found** in rule
ObservedDef_Waistband (True).
Condition **Curr_Defect.Location** is *"Waistband"* in rule
ObservedDef_Waistband_Right_End (True).
Waistband_Length is set to *True*
Condition there is evidence of **Waistband_Length** in rule
ObservedDef_Waistband (True).
Rule 7 is set to true
Attach_Waistband is set to *True*
RHS: **Curr_Defect.Mfg_Operation** is set to *"Attach_Waistband"*
in rule ObservedDef_Waistband
Curr_Defect.Mfg_Operation is set to Attach_Waistband
RHS: **<|SpecClass_Attach_Waistband|>.Admissible_Spec** is set to *TRUE*
in rule ObservedDef_Waistband
Spec_Attach_Waistband_And_Size_Label_1.Admissible_Spec
is set to *TRUE*
Spec_Attach_Waistband_And_Size_Label_23.Admissible_Spec
is set to *TRUE*
Spec_Attach_Waistband_And_Size_Label_2a.Admissible_Spec
is set to *TRUE*
Spec_Attach_Waistband_And_Size_Label_2b.Admissible_Spec
is set to *TRUE*
Spec_Attach_Waistband_And_Size_Label_5.Admissible_Spec
is set to *TRUE*
Spec_Attach_Waistband_And_Size_Label_5.Admissible_Spec
is set to *FALSE* in rule ObservedDef_Waistband
RHS: **Location_Found** is set to *TRUE* in rule ObservedDef_Waistband
Location_Found is set to *True*

SECTION B
Rejection of Defect Locations

Rule 5 is set to false
Rule 6 is set to false
Attach_Right_Fly_To_Right_Front is set to *False*
Rule 4 is set to false
Attach_Patch_Pockets is set to *False*
. . . .
. . . .

SECTION D
Rejection of Incorrect Defect Types

Rule 62 is set to false
Rule 61 is set to false

Wrong_Or_Irregular_Stitch_Gauge is set to *False*
Rule 60 is set to false
Rule 59 is set to false
Uneven_Stitch_Line is set to *False*
Rule 58 is set to false
Rule 57 is set to false
Twisted_Seam is set to *False*

SECTION E
Level Two Rules

Condition **Curr_Defect.Type** is "*Skipped Stitch*" in rule Skipped_-
Stitch_In_Specific_Location (True).
Condition there is no evidence of **Curr_Defect.Diagnosis_Done** in
rule Skipped_Stitch_In_Specific_Location (True).
<|Skipped_Stitch|>.specific_operation=Skipped_Stitch_Attach_Belt_
Loops,Skipped_Stitch_Attach_Label,Skipped_Stitch_Attach_Patch_Poc
kets,Skipped_Stitch_Attach_Waistband_Left_End,Skipped_Stitch_Inse
am,Skipped_Stitch_Make_Belt_Loops,Skipped_Stitch_Make_Left_Fly,Sk
ipped_Stitch_Make_Right_Fly,Skipped_Stitch_Outseam
Condition **<|Skipped_Stitch|>.specific_operation** is equal to **Cur-
r_Defect.Mfg_Operation** in rule Skipped_Stitch_Def_In_Specific_O-
peration (False).
Rule 56 is set to false
Condition **Curr_Defect.Type** is "*Skipped_Stitch*" in rule Skipped_-
Stitch_Defect (True).
Condition there is no evidence of **Curr_Defect.Diagnosis_Done** in
rule Skipped_Stitch_Defect (True).
Rule 55 is set to true
Skipped_Stitch is set to *True*
RHS: Show "*causes/ss/ss*" @KEEP=TRUE;@WAIT=FALSE; in rule Skipped_-
Stitch_Defect
RHS: **Curr_Defect.Diagnosis_Done** is set to TRUE in rule Skipped_-
Stitch_Defect
Curr_Defect.Diagnosis_Done is set to *True*

SECTION D
Rejection of Incorrect Defect Types

Rule 52 is set to false
Rule 51 is set to false
Run_Off is set to False
. . . .
. . . .

Rule 12 is set to false
Rule 11 is set to false
Broken_Thread is set to False

SECTION F
Display Relevant Construction Specifications

Condition there is evidence of **Curr_Defect.Diagnosis_Done** in rule 54 (True).
View_Spec is set to *True*
Condition there is evidence of **View_Spec** in rule 54 (True).
Rule 54 is set to true
Select_SpecClass is set to *True*
RHS: STRCAT("*SpecClass_*",**Curr_Defect.Mfg_Operation**) is assigned to **Curr_Defect.Construction_Spec_Group** in rule 54
Curr_Defect.Construction_Spec_Group is set to SpecClass_Attach_-Waistband
RHS:**<\Curr_Defect.Construction_Spec_Group\>.Operationally_Relevant_Spec** is set to TRUE in rule 54
Spec_Attach_Waistband_1.Operationally_Relevant_Spec is set to *True*
Spec_Attach_Waistband_23.Operationally_Relevant_Spec is set to *True*
Spec_Attach_Waistband_2a.Operationally_Relevant_Spec is set to *True*
Spec_Attach_Waistband_2b.Operationally_Relevant_Spec is set to *True*
Spec_Attach_Waistband_5.Operationally_Relevant_Spec is set to *True*
Condition there is evidence of **<\Curr_Defect.Construction_Spec_-Group\>.Admissible_Spec** in rule 53 (True).
Condition there is evidence of **<\Curr_Defect.Construction_Spec_-Group\>.Operationally_Relevant_Spec** in rule 53 (True).
Rule 53 is set to true
Select_Spec_87062 is set to *True*
RHS: Execute "*spec_read*" (@STRING="*@V(Curr_Defect.Construction_-Spec_Group*"); in rule 53
RHS: Show "*specfile*" @KEEP=TRUE;@WAIT=TRUE; in rule 53

Figure 9.1b   Transcript of a Diagnostic Session for a Skipped Stitch Defect on the Waistband

dedicated to the right end of the waistband. However, that is not where the problem is located, so the matcher continues to a rule which searches for a Location on the left-hand side of the waistband. There is no success there, either.

SDAS then comes to a pattern matching success at the rule which inquires about a defect somewhere along the length of the waistband. This rule then sets the hypothesis "Attach_Waistband" to be true, and proceeds to execute the RHS clauses of the rule. The manufacturing operation most likely to give rise to this defect is set to be "Attach_Waistband"; the entire class of specifications from MIL-STD-87062A dealing with this operation of attaching the waistband to the trouser is deemed as admissible norms. Out of this group of specifications, one is then reset by this rule as uninteresting. (In this case, this specification is discarded because it deals with a process not relevant for a defect along the length of the waist band).

SDAS continues further to reset the remaining Location possibilities (Section B). It must be noted that global hypothesis-class rejection schemes such as those used in FDAS are unnecessary at this point in the development of SDAS, because of the very limited number of defect locations that SDAS has to deal with.

Level Two Rules: At the second level, the system's focus shifts to identifying the nature of the defect, analyzing it and suggesting remedies. Section D in Figure 9.1b shows SDAS removing other defect types from consideration. In Section E, the two rules which share the same "Skipped_-Stitch" hypothesis are activated Since the more specific rule has a higher priority, the transcript shows the Level 2(a) rule being considered first.

The rule comes to its third clause on the LHS, and expands the Skipped Stitch Class into its children objects. These directly correspond to specific diagnosis scripts available for different operations. If there is no specific diagnosis script for a particular manufacturing operation, there will be no corresponding child object in that defect type class. Now, SDAS looks to see if there is any match between any of the list's elements and the current manufacturing operation. In the current example, the software finds none. That is, there is no specific diagnosis file such as "ssawb" in the directory "ss", which would be the diagnosis information to supplement the generalized set of recommendations in the file "ss". The rule thereby fails at this list expansion and matching stage for rule 2(a).

SDAS proceeds to the lower priority rule in its queue. The matching conditions here are a simple subset of those of rule 2(a). Therefore rule 2(b) acts, in the transcript Section E, and causes the hypothesis *Skipped_Stitch* to be set to true. The generalized defect diagnosis file "ss" in the directory "ss" is displayed to the user, and the flag is set to indicate that the defect has been successfully analyzed. Other defect type rules are scanned in quick sequence and their hypotheses discarded.

Finally, the group of specification display rules acts and queries the user to see if the relevant set of norms and recommendations from the construction specifications need to be displayed. This is done by the question associated with atom *View_Spec*. If the user answers in the affirmative, the rules begin by synthesizing the name of the group of construction specifications from the Manufacturing Operation determined earlier in Level One processing. As in Section F of Figure

9.1b, this is assigned to the slot 'Curr_Defect.Construction_Spec_Group', and all the specification entries (objects in the class with the specification's Name) are labelled as operationally relevant.

Another rule then checks these objects, each representing a specification declared as currently of interest, to see if the specification is of interest to the user. This is done by checking the *Operationally_Relevant_Spec* slot of the spec objects.These slot values are directly set by the user in the knowledge base. All the relevant specifications are concatenated by calling a C function and then displayed by SDAS.

Another Example: Figure 9.2 shows the two levels of rules used for illustrating the second example, namely, where the user sees an Open Seam at the double-lapped join of the crotch seam. The symmetry between the defect location and type rules seen in Figures 9.1a and 9.2 is readily apparent. This greatly helps modularity and ease of future modifications and enhancements. Also, the rules for defect location (which will be subject to the greatest flux, e.g., new rules for new garments) and those for defect type identification and analysis are completely compartmentalized.

The Level One rules work precisely as before, using the user-supplied location of "Crotch_-Seam". The pattern matching commences and discards location hypotheses till a rule trying to assert the "Join_Crotch_Seam" hypothesis is encountered. All the LHS clauses prove correct, and this hypothesis is confirmed. (In fact, the pattern matching task is even easier than in the previous example, where there were three rules attempting to localize the defect somewhere on the waistband assembly). Since only one manufacturing operation could be responsible for an assembly operation defect such as an Open Seam, the 'Curr_Defect.Mfg_Operation' is filled with the data "Join_Crotch_Seam". Every member of the class of specifications from MIL-STD-87062A dealing with this operation is also marked as being of interest. A flag is set to inform other rule subsets within SDAS that the current defect's location has been correctly absorbed. The system then discards all other defect location possibilities.

The Open Seam defect hypothesis is provable by two rules at the second Level (Figure 9.2). Since the more specific rule for this defect hypothesis has a higher priority, it will act first. On the LHS of the rule, the first two conditional clauses are satisfied. The third conditional clause checks if any object belonging to the class *Open_Seam* matches the data filling the slot *Curr_Defect.Mfg_Operation*, i.e., "Join_Crotch_Seam". If there is a match, it signifies that there is specific information on the causes and remedies for an Open Seam defect at Crotch Seam location.

Unlike the previous example, a match is found; that is, there is an object whose *specific_-operation* slot has the same contents "Join_Crotch_Seam". The name of this object is Open_Seam_Join_Crotch_Seam, and its *op_code* or slot contains data "jcs". The rule is therefore successful in confirming its hypothesis. The RHS actions are now commenced, the last of which will set a flag that will inform all subsequent processing of the completion of the diagnosis. (This also disables the general rule 2(b) for Open_Seam in Figure 9.2, which is waiting in the rule priority queue, because there is no use for it after this point).

The first RHS action assigns the "os" type code to the atom Curr_Defect. The next RHS action synthesizes an "Operation Vector", using the type code "os" and the operation code extracted from the list-matched object. In this case, the object is Open_Seam_Join_Crotch_Seam, and its

LEVEL 1 : *Rule* ObservedDef_Waistband
If there is no evidence of **Location_Found**
And **Curr_Defect.Location** is *"Crotch_Seam"*
    Then **Join_Crotch_Seam** is confirmed.
And **|Curr_Defect|.Mfg_Operation** is set to *"Join_Crotch_Seam"*
And **<|SpecClass_Join_Crotch_Seam|>.Admissible_Spec** is set to *TRU*
And **Location_Found** is set to *TRUE*

LEVEL 2 (a): *Rule* Open_Seam_Def_In_Specific_Operation;
                PRI= -100;
If **Curr_Defect.Type** is *"Open_Seam"*
And there is no evidence of **Curr_Defect.Diagnosis_Done**
And **<|Open_Seam|>.specific_operation** matches
Curr_Defect.Mfg_Operation
    Then **Open_Seam** is confirmed.
And **|Curr_Defect|.type_code** is set to *"os"*
And **|Curr_Defect|.OpVector** is set to
STRCAT(Curr_Defect.type_code, <|Open_Seam|>.op_code)
And *"concat"* is **Executed**
And *"tempfile"* is **Shown** (@KEEP=TRUE,@WAIT=FALSE)
And **Curr_Defect.Diagnosis_Done** is set to *TRUE*

LEVEL 2 (b): *Rule* Open_Seam_Defect
If **Curr_Defect.Type** is *"Open_Seam"*
there is no evidence of **Curr_Defect.Diagnosis_Done**
    Then **Open_Seam** is confirmed.
And *"causes/cs/os"* is **Shown** (@KEEP=TRUE,@WAIT=FALSE)
And **Curr_Defect.Diagnosis_Done** is set to *TRUE*

Figure 9.2   Two Levels of Rules for an Open Seam when Joining the Crotch Seam

op_code field or slot contains data "jcs". Therefore, the concatenation of these will result in a string "osjcs" in the slot *OpVector* of atom Curr_Defect. An external procedure called *concat* is called to bring together the contents of the generalized diagnosis file "os" in the directory "os" as well as the contents of the file "osjcs", which is additional information concerned with Open Seams only at this operation of Joining Crotch Seams. The result is put into file "tempfile" which is then displayed by the next RHS action.

9.2 Speed and Size of SDAS

Just as in the case of FDAS, it is extremely important that SDAS' response be as fast as possible since it is to be used by the garment inspector on the shopfloor.

Response Time

It has an advantage over FDAS as it needs only two defect characteristics from the user, viz., defect type and defect location (as opposed to five characteristics required by FDAS). SDAS displays menus for user input of the defect's visual characteristics almost instantaneously. Most diagnosis sessions take 2-4 seconds after user input has been completed to display the analysis and recommendations. In case the user desires to see the MIL specs, the system displays them in 2-3 seconds. Even for defect subclasses where the system asks further questions to pinpoint the manufacturing process responsible for the defect, the overall session time is about 15-20[1] seconds.

Size of the Knowledge Base

SDAS has fewer rules compared to FDAS: only 70 rules, including the ancillary control rules for writing defect information out to the database. This was accomplished by exploiting the rich pattern matching and logical operators available in Nexpert in conjunction with the class structure. There is a trade-off, however, in that the class-object hierarchy is complex.

9.3 Modularity and Ease of Customization

The diagnostics information is contained in text files, as in the case of FDAS. Hence, users can customize the system output to their requirements without affecting the working of the rest of the system. The directories containing the diagnosis files have been structured to exactly mimic the defects class structure. Hence, it is easy for the user to make modifications at the right place.

On the other hand, making modifications to the knowledge base itself requires more knowledge engineering when compared to FDAS. The basis of classification, viz., nature of the defect and the location of the defect are applicable to all garment types. However, since the possible locations are entirely different for different garment types, the defect class hierarchy will be different for different garments.

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1. All the times mentioned are for the DOS version; the UNIX version takes slightly shorter times as all the data needed for the system are entered within a single form.

CHAPTER 10

DATABASE INTEGRATION WITH FDAS AND SDAS

FDAS and SDAS have knowledge about fabric and sewing defects and can help users in identifying a defect accurately and in taking appropriate remedial actions. In addition to these, there is a need to monitor long- and short-term trends in defect occurrences for effective quality control. To do this, data about defect occurrences is to be recorded in a database, which can be used for generation of reports in any required form. Information about defects is represented in the form of objects and object attributes in the knowledge bases. In a relational database, it has to be maintained in a table in the form of records and fields. Nexpert Object allows dynamic communication with databases by linking object attributes to fields in a table. Currently, FDAS and SDAS have been made to write data to an Oracle relational database. Nexpert Object can also be linked to a number of other flat-file and relational databases.

10.1 Database Schema

Figure 10.1a shows the database table used to record information about sewing defects. The first field (column) in the table identifies a defect occurrence uniquely and hence is called the *key* to the table. Starting from left, two digits each are used to represent the month, date, year, hour, minute and second at which the defect was recorded. For example, the first defect in the table was recorded in the month of January, on the 15th, in the year '92, at 12 minutes and 11 seconds past 8 a.m. The second field is the identification number assigned to the bundle and is an alpha-numeric string. This is useful in tracing the defect to the cut or bundle. The third field shows the part of the garment where the defect was found. This and the information in the last field, viz., type of the defect were volunteered by the user to SDAS. The fourth field shows the manufacturing operation which could have caused the defect. This information is the outcome of inferencing by SDAS. Defects can be sorted on any of the fields and summary data can be generated. For example, the database can be queried for defect occurrences due to a particular manufacturing operation or on defects of a particular type.

The database table for FDAS is shown in Figure 10.1b. The time of occurrence is again used as the key. Other information contained in the database are the style number of the fabric, the descriptive name of the defect, and the direction of occurrence of the defect (length, width or no preferred orientation).

10.2 Communication with the Database

Writing information to the database is triggered by rules in the knowledge base. Figure 10.2a shows the two rules in SDAS leading to the recording of defects data. The first condition for Rule 19, **Curr_Defect.diagnosis_Done**, is set to true by rules which identify different individual defects (e.g., Level 2 (a) in Figure 9.2). At the beginning of a session, the user is asked if defect information is to be written to the database. If the user had answered in the affirmative, the second condition, **DBtransact.writeflag** would have been set to true. Once these two conditions are satisfied, **Get_curr_time** is set to true, which in turn causes Rule 14 to fire. Also

TIMEDATE	BUNDLE-ID	DEF_LOCATION	MFG_OPERATION	DEF_TYPE
011592081211	DT149725	BELT_LOOP	ATTACH_BELT_LOOP	BROKEN_THREAD
011592092319	BX229374	PATCH-POCKET	MAKE_PATCH_POCKET	OPEN_SEAM

Figure 10.1a Database Table for SDAS

TIMEDATE	STYLE_NUM	DEF_DESC	DEF_DIR
122391112416	HD152944	COARSE_YARN	WARP
122391121734	BG598423	THCK_PLACE	FILLING

Figure 10.1b Database Table for FDAS

```
RULE : Rule 19
If       there is evidence of Curr_Defectiagnosis_Done
         there is evidence of DBtransact.writeflag
Then     Get_curr_time is confirmed.
         And Execute "timestamp"()


RULE : Rule 14
If       there is evidence of Get_curr_time
Then     Database_Trigger is confirmed.
         And <|FabricDefects|>.Type assigned to CurrDef.ObsName
         And Writing in
         "@V(DBtransact.username)@V(DBtransact.userpassword)"
         @TYPE=ORACLE;@FILL=ADD;@END="COMMIT";@NAME="!TIMEDATE!"
         @PROPS=Time_and_Date,OpVector,Location,Mfg_Operation,
         Type;
         @FIELDS="TIMEDATE","BUNDLE_ID","DEF_LOCATION",
         "MFG_OPERATION","DEF_TYPE";
         @QUERY="SEW_DEF";@ATOMS=CurrDef;
```

Figure 10.2a Rules for Accessing the Database from SDAS

```
RULE : Rule 176
If       there is no evidence of Diagnosis_Pending
         there is evidence of DBtransact.writeflag
Then     Get_curr_time is confirmed.
         And Execute "timestamp"()


RULE : Rule 154
If       there is evidence of Get_curr_time
Then     Database_Trigger is confirmed.
         And <|FabricDefects|>.Type assigned to CurrDef.ObsName
         And Writing in
         ` @V(DBtransact.username)@V(DBtransact.userpassword)"
         @TYPE=ORACLE;@FILL=ADD;@END="COMMIT";@NAME="!TIMEDATE!"
         @PROPS=ObsType,ObsName,ObsDir,Time_and_Date;
         @FIELDS="STYLE_NUM","DEF_DESC","DEF_DIR","TIMEDATE";
         @QUERY="FAB_DEF";@ATOMS=CurrDef;
```

Figure 10.2b Rules for Accessing the Database from FDAS

the function "timestamp" is executed, which forms the "TIMEDATE" string in a form described in the previous section.

Rule 14 has a list of knowledge base properties (following @**PROPS**=) which are to be recorded in a database, and another list of the fields in the database table (following @**FIELDS**=) which will hold these properties. The elements of the two lists have one-to-one correspondence. The name of the database table, viz., "SEW_DEF," is shown as the value of @**QUERY** and that of the atom whose properties are to be recorded is shown as the value of @**ATOMS**. "@**TYPE**=ORACLE" sets the database type; "@FILL=ADD" causes new records to be added to the end of the table; "@END="COMMIT"" instructs the database management system to write the record permanently (commit) once the transaction is complete; and "@NAME="!TIMEDATE!"" indicates that TIMEDATE is the key to the table SEW_DEF. "DBtransact.username" is the user-id and "DBtransact.userpassword" is the password for the user, and these must have been set by the database administrator.

For FDAS, a similar scheme is used to write information to a database table called FAB_DEF (Figure 10.1b). The rules triggering this process are shown in Figure 10.2b.

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions that can be drawn from the research carried out and discussed in the previous chapters. Recommendations for further development work on FDAS and SDAS are also presented.

11.1 Conclusions

Two separate knowledge-based systems -- FDAS and SDAS -- have been developed for analysis of denim fabric and utility trouser manufacturing defects, respectively. In addition to being useful for analysis of defects, these systems will be effective tools to train fabric and garment inspectors and other quality control personnel.

Both the systems employ novel schemes for classifying defects, based only on the visual attributes of the defects. The important advantage of these schemes is that they do not require prior knowledge of the defect. Consequently, the scheme can be used as an underlying framework for an automatic (vision-based) fabric inspection system.

FDAS identifies a defect uniquely after a five- or six-stage search process. The system response is fast and is not expected to delay the operator's task on the shopfloor. SDAS identifies a defect after a two- or three-stage search process and is also fast in its response.

Both the systems can be easily tailored for the special needs of any individual organization as the diagnosis information can be altered independently of the remainder of the system. Other system design objectives such as flexible user interface and effective separation of domain and control knowledge have also been achieved.

The systems have been extensively tested in-house and have been demonstrated to experts, and they are ready for in-plant testing.

11.2 Recommendations

Both knowledge bases have been designed to accommodate extensions to other product types. Extension of FDAS to analyze other fabrics (besides denims) will not only be useful, but also can be accomplished without many changes to the current knowledge base. Likewise, the scope of SDAS can be broadened to other garments (besides utility trousers).

FDAS should be tested as a backend to vision-based defect detection systems, such as the one recently announced by ELBIT Vision Systems of Israel.

Attempts have been made to keep the verbal description of defects easy to understand by using a consistent description scheme with limited number of attributes. However, a pictorial r p-

resentation of defects is expected to reduce possible ambiguities associated with verbal descriptions. This task requires collection of fabric defect samples and developing means to display both the fine details, such as *appearance*, and global details, such as *orientation* and *pattern of repeat*, on a computer terminal.

Both the systems should be tested in textile/apparel plants.

***

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APPENDIX A

Defects Questionnaires
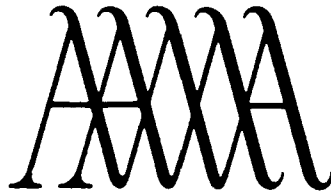
AMERICAN APPAREL MANUFACTURERS ASSOCIATION

August 1, 1989

Dear AAMA Member:

Our Association is pleased to support two research projects currently in progress at Georgia Tech under the direction of Dr. Sundaresan Jayaraman for the U.S. Defense Logistics Agency. As you can see from the enclosed background papers, these projects are of considerable interest to our community and we will stand to benefit from them. The researchers have developed three questionnaires for these projects and are looking to our industry for information and input.

The first project is in the area of <u>defects in apparel manufacturing</u> and there are two questionnaires for this project. The short one is for an overall economic assessment of defects, while the long one is for a detailed analysis of defects. They can best be answered by quality control and/or manufacturing personnel.

The second project is in the area of <u>contractor evaluation</u> and there is one questionnaire for this project. It can best be answered by your contracting personnel.

If your firm is not experienced in either matter, please discard these surveys. If your experience and input might be beneficial to the research study, please have knowledgeable individuals from your firm complete the surveys and return them <u>directly</u> to the address given below. The enclosed background papers will help the individuals in responding to the surveys. If you have any questions on the projects, please feel free to call Sundaresan at 404/894-2490.

Your cooperation in these studies is greatly appreciated. **Please return the surveys before September 6, 1989 to**

> Dr. Sundaresan Jayaraman
> School of Textile Engineering
> Georgia Institute of Technology
> Atlanta, Georgia 30332
> Fax: 404/894-8780

Cordially,

Fred B. Shippee
Director of Technical Services

2500 Wilson Boulevard/ Suite 301/ Arlington, Virginia 22201 • 703/524-1864 • FAX 703/522-6741

ANALYSIS OF DEFECTS IN APPAREL MANUFACTURING

QUESTIONNAIRE

AUGUST 1989

Please note: Neither your name nor that of your company will be published or released to anyone. All the information will be used for analysis only.

Please return the questionnaire to:

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Tel: 404/894-2490
FAX: 404/894-8780

Research Background

Quality is free and defects cost money. Georgia Tech has undertaken research in the School of Textile Engineering aimed at developing a knowledge-based system for the analysis of defects in apparel manufacturing. A knowledge-based framework (commonly referred to as an expert system) is an intelligent computer program that will assist apparel manufacturers in identifying the sources for the various types of defects (*e.g.*, fabric, sewing) and the remedies for minimizing them. The key to the development of such a system is the knowledge base, *i.e.*, the criteria, rules and scheme used for the classification and prevention of defects. Yet another objective of the research endeavor is to assess the economic impact of defects in apparel manufacturing, *i.e.*, the loss of sales due to second quality garments and loss of productive time due to reworking.

The Questionnaire

The purpose of the enclosed questionnaire is to solicit your expert opinion on defects in garment manufacturing based on your experience. The listed questions may miss some points that you feel are important. You are invited to correct this by adding comments freely. Your input is extremely valuable and urgently needed.

In return for your help, you will be offered the opportunity to receive a copy of the results of the questionnaire. The computer programs can also be made available to you and your company for your use. See the end of the questionnaire for more details. Also, if another person in your organization can offer their experience to this questionnaire, please notify us to secure additional copies or copy this one for them. Thank you for assisting us in reaching as many experts as is possible.

Research Sponsor

This research is being sponsored by the Defense Logistics Agency (DLA) in the Department of Defense. The DLA procures approximately $1.6 billion worth of apparel every year and is funding this research to promote the production of quality goods and to enhance the overall state of the textile and apparel industries in the United States.

Confidentiality of Information

The researchers recognize the importance of the information furnished by you. The information will be utilized for research purposes only and the **company name will be kept confidential.**

1. This Questionnaire is designed to seek information on defects encountered in the apparel manufacturing process, specifically, trouser manufacturing. If you are not a trouser manufacturer, please identify below the **major product** of your company and fill in information **only** for this product.

   Information furnished is for product (*e.g.,* shirts, lingerie, etc.): _____

2. <u>CLASSIFICATION OF DEFECTS:</u>   The following example illustrates one way of classifying defects found in assembled garments. This example, in fact, is a strict reproduction of the classification scheme outlined in the military standard, MIL-STD-105D and used extensively for government and military procurement purposes.

   <p style="text-align:center">DEFECTS IN ASSEMBLED GARMENTS</p>

CRITICAL	MAJOR	MINOR
A critical defect is one that could lead to hazardous and unsafe conditions during usage.	A major defect is one that is essentially non-critical but could result in premature failure or in reduced life.	A minor defect is one that does not materially reduce the usability of the product nor will it have a significant effect on the use or operation of the product.
<u>Examples</u>: Inadequate flame retardancy, toxic finish, etc.	<u>Examples</u>: Two or three skipped or broken stitches, visible hole or holes in the garment, etc.	<u>Examples</u>: Occasional skipped or broken stitch, slightly irregular stitch gauge, etc.

A. Use the above illustration as an example and list the broad categories into which defects in assembled trousers (or your major product) are classified in your own organization. For each category you use, clearly state the factors or criteria that are used to assign defects to that category. If you use a Point System, please list each point value under "category" and list the factors or criteria that determine their assignment.

   If you already have this information in printed form, please insert a copy here and go on to section B (page 5). If you do not classify defects at all, skip to Question 3 (page 7).

Category	Criteria

B.   For each category you identified above, please list all the individual defects that fall within that category.

     If you already have the necessary information in printed form, simply insert it here in the questionnaire and go on to Question 3.

Category   **Defects**

_____   _____

_____   _____

                                _____

                                _____

_____   _____

                                _____

                                _____

_____   _____

                                _____

_____   _____

                                _____

                                _____

_____   _____

                                _____

_____   _____

                                _____

Category   **Defects**

3.   RAW MATERIAL TESTING:

A number of properties of fabric and trim are listed below. Note that there are five groups of properties -- one each for fabric, thread, buttons, zippers, and lining materials. For each property in each group, please answer the following queries:

a.   Do you specify this property when you place the order?

b.   Do you physically test the fabric or trim for this property when it arrives? If you do not test fabric or trim for this property, skip to the next property.

c.   What is your average lot size (*e.g.*, 1,000 yards of fabric, a gross of buttons)?

d.   When you test for this property, what is your average sample size per lot? Please be specific about the unit of measure (*e.g.*, 5 yards per bolt, 10 buttons per gross).

e.   What is the standard value for this property?

f.   What is an acceptable tolerance for this property? Please specify this in either units (*e.g.*, 5 yards per thousand) or percent.

Please use an "X" mark in the parentheses, to indicate **YES**, in the appropriate column. Fill in the blanks in the other columns. If you use an ASTM standard for testing of a property, please specify the test number in the last column.

FABRIC

Properties	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole- rance	ASTM number
Ends/Picks	( )	( )	___	___	___	___	___
Weave	( )	( )	___	___	___	___	___
Weight	( )	( )	___	___	___	___	___
Thickness	( )	( )	___	___	___	___	___
Finish	( )	( )	___	___	___	___	___
Width	( )	( )	___	___	___	___	___

Fabric Properties (cont.)	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole-rance	ASTM number
Color/Shade Fastness	( )	( )	____	____	____	____	____
Crease Resistance	( )	( )	____	____	____	____	____
Pilling Resistance	( )	( )	____	____	____	____	____
Crock Fastness	( )	( )	____	____	____	____	____
Shrinkage	( )	( )	____	____	____	____	____
Strength:							
tensile	( )	( )	____	____	____	____	____
tearing	( )	( )	____	____	____	____	____
bursting	( )	( )	____	____	____	____	____
Abrasion Resistance	( )	( )	____	____	____	____	____
Flexural Rigidity	( )	( )	____	____	____	____	____
Air Permeability	( )	( )	____	____	____	____	____
Wash and Wear Performance	( )	( )	____	____	____	____	____
Any Other Fabric Properties							
_____	( )	( )	____	____	____	____	____
_____	( )	( )	____	____	____	____	____
_____	( )	( )	____	____	____	____	____

THREAD

Properties ber	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole-rance	ASTM num-
Blend	( )	( )	___	___	___	___	___
Count	( )	( )	___	___	___	___	___
Twist	( )	( )	___	___	___	___	___
Ply	( )	( )	___	___	___	___	___
Color Fastness	( )	( )	___	___	___	___	___
Strength: loop	( )	( )	___	___	___	___	___
tensile	( )	( )	___	___	___	___	___
Elongation	( )	( )	___	___	___	___	___
Twist Liveliness	( )	( )	___	___	___	___	___

BUTTON

Properties ber	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole-rance	ASTM num-
Compressive Strength	( )	( )	___	___	___	___	___
Heat Resistance	( )	( )	___	___	___	___	___
Water Resistance	( )	( )	___	___	___	___	___
Color Fastness	( )	( )	___	___	___	___	___
Weight	( )	( )	___	___	___	___	___
Shape Uniformity	( )	( )	___	___	___	___	___

ZIPPER

Properties	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole-rance	ASTM num-ber
Heat Resistance	( )	( )	___	___	___	___	___
Water Resistance	( )	( )	___	___	___	___	___
Color Fastness	( )	( )	___	___	___	___	___
Cycles to Failure	( )	( )	___	___	___	___	___

LINING MATERIALS

Properties	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole-rance	ASTM num-ber
Fiber Blend Composition	( )	( )	___	___	___	___	___
Weight	( )	( )	___	___	___	___	___
Construction (Woven or Nonwoven)	( )	( )	___	___	___	___	___
Strength: tensile	( )	( )	___	___	___	___	___
tear	( )	( )	___	___	___	___	___
Breaking Elong.	( )	( )	___	___	___	___	___
Thickness	( )	( )	___	___	___	___	___
Flexural Rigidity	( )	( )	___	___	___	___	___

MISCELLANEOUS

Properties ber	Specified In Order	Physically Tested	Lot Size	Sample Size	Std. Value	Tole- rance	ASTM num-
_____	( )	( )	___	_____	_____	_____	____
_____	( )	( )	___	_____	_____	_____	____

4. **TYPES OF FABRICS USED:** Below are listed the major types of primary (shell) and lining fabrics -- wovens, nonwovens and knits. For each type of fabric, please indicate:

i.   What **percentage** of the fabric you purchase is of each type?

ii.   What is the **average cost per yard** for each?

iii. What **percentage** of the yardage you purchase represents each of the fiber types indicated?

PRIMARY FABRICS

FABRIC TYPE	% OF PURCHASES	AVG. $/YD	FIBER TYPE (%)			
			WOOL	SYNTHETICS	COTTON	BLENDS
Wovens	_____	_____	_____	_____	_____	_____
Knits	_____	_____	_____	_____	_____	_____

LINING FABRICS

FABRIC TYPE	% OF PURCHASES	AVG. $/YD	FIBER TYPE (%)			
			WOOL	SYNTHETICS	COTTON	BLENDS
Wovens	_____	_____	_____	_____	_____	_____
Nonwovens	_____	_____	_____	_____	_____	_____

5. RAW MATERIAL DEFECTS: A number of defects in **raw materials** are listed below. For each defect listed, please answer the following:

    i. What percentage of the material you inspect contains this defect? Include only defective material that is identified during the **raw materials inspection stage.** If you do <u>not</u> inspect raw materials, <u>skip to Question 6.</u>

    ii. What is your best estimate of the total dollar loss due to this defect in 1988, at the **raw material inspection stage?** If you cannot estimate the dollar amount, please rank the extent of the monetary loss on a *scale from one to five*, where *one* means "An Insignificant Loss" and *five* means "A Very Significant Loss".

Please list any other defects in raw materials that may not be included below and provide similar information for these defects as well.

FABRIC DEFECTS

DEFECTS	DEFECTS AS A % OF TOTAL MATERIAL INSPECTED	VALUE LOSS DUE TO MATERIAL DEFECTS ($ / YEAR)	INSIG-NIFICANT LOSS			VERY SIGNIFICANT LOSS	
Color variation (per yd.)							
- side to side	_____	_____	1	2	3	4	5
- yard to yard	_____	_____	1	2	3	4	5
- lot to lot	_____	_____	1	2	3	4	5
Visible defects (per yd.)							
- holes	_____	_____	1	2	3	4	5
- stains	_____	_____	1	2	3	4	5
- missing threads	_____	_____	1	2	3	4	5
- warp streaks	_____	_____	1	2	3	4	5
- filling defects	_____	_____	1	2	3	4	5
- spot defects (slubs, neps, etc.)	_____	_____	1	2	3	4	5
- bad selvage	_____	_____	1	2	3	4	5
- pilling	_____	_____	1	2	3	4	5
- reed marks	_____	_____	1	2	3	4	5
- mixed ends	_____	_____	1	2	3	4	5
Width variation							
- yard to yard (per yd)	_____	_____	1	2	3	4	5
- roll to roll	_____	_____	1	2	3	4	5
Improper finish							
- poor hand (per yd)	_____	_____	1	2	3	4	5
- printing defects (if applicable)	_____	_____	1	2	3	4	5

| | - not meeting specs for water repellency, etc. | _____ | _____ | 1 | 2 | 3 | 4 | 5 |
| **High shrinkage (per yd.)** | | _____ | _____ | 1 | 2 | 3 | 4 | 5 |

Others (specify)

_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5

TRIM DEFECTS

DEFECTS	DEFECTS AS A % OF TOTAL TRIM INSPECTED	VALUE LOSS DUE TO TRIM DEFECTS ($ / YEAR)	INSIG-NIFICANT LOSS				VERY SIGNIFICANT LOSS
- buttons broken/poor strength (per gross)	_____	_____	1	2	3	4	5
- buttons of wrong color (per gross)	_____	_____	1	2	3	4	5
- bad zippers (per yd.)	_____	_____	1	2	3	4	5
- others (specify)							
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5

6. FINISHED GOODS DEFECTS: A number of defects in **finished goods** are listed below. They are organized into four groups - manufacturing defects, material defects, trim defects, and miscellaneous defects.   For each defect listed, please answer the following:

   i.   What percentage of the **finished goods** you inspect contains this defect? Include only defective items that are identified during the **finished goods inspection stage**. If you do not inspect finished goods, skip to Question 6.

   ii.   What is your best estimate of the total dollar loss due to this defect in 1988, at the **finished goods inspection stage**? If you cannot estimate the dollar amount, please rank the extent of the monetary loss on a scale from one to five, where one means "An Insignificant Loss" and five means "A Very Significant Loss".

Please list any additional defects in finished goods that are not included below and provide similar information.

MANUFACTURING DEFECTS

DEFECTS	DEFECTS AS A % OF TOTAL UNITS PRODUCED	VALUE LOSS DUE TO MANUFACT. DEFECTS ($ / YEAR)	INSIG-NIFICANT LOSS				VERY SIGNIFICANT LOSS
Spreading Defects							
- tight or slack, incorrect overlap, etc.	_____	_____	1	2	3	4	5
- improper folds	_____	_____	1	2	3	4	5
- wrong side up	_____	_____	1	2	3	4	5
Cutting defects							
- frayed edges	_____	_____	1	2	3	4	5
- fused or scorched edges	_____	_____	1	2	3	4	5
- ragged, serrated or fuzzy edges	_____	_____	1	2	3	4	5
- improper size	_____	_____	1	2	3	4	5
- improper notches	_____	_____	1	2	3	4	5
- rips or pulled yarns	_____	_____	1	2	3	4	5
- incorrect bundle identification	_____	_____	1	2	3	4	5
- skipped stitches	_____	_____	1	2	3	4	5
- stitching distortion (puckering, etc.)	_____	_____	1	2	3	4	5
- improper stitch size	_____	_____	1	2	3	4	5
- yarn severance	_____	_____	1	2	3	4	5
- improper stitch width, letout	_____	_____	1	2	3	4	5
- seam slippage	_____	_____	1	2	3	4	5
- other (specify)							
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
Soiled garments	_____	_____	1	2	3	4	5
Pressing Defects							
- fusion or scorching	_____	_____	1	2	3	4	5
- shine due to mechanical pressure of the contacting ram buck	_____	_____	1	2	3	4	5

MANUFACTURING DEFECTS (cont.)	DEFECTS AS A % OF TOTAL UNITS PRODUCED	VALUE LOSS DUE TO MANUFACT. DEFECTS ($ / YEAR)	INSIG-NIFICANT LOSS			VERY SIGNIFICANT LOSS	
Defective Pockets							
- misaligned/misplaced	_____	_____	1	2	3	4	5
- other (specify)							
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
Fit / Form							
- incorrect size	_____	_____	1	2	3	4	5
- incorrect plaid or stripe matching	_____	_____	1	2	3	4	5
- poor drape	_____	_____	1	2	3	4	5
Shrinkage	_____	_____	1	2	3	4	5
Leg bottom							
- poorly finished or stitched	_____	_____	1	2	3	4	5
- twisted legs	_____	_____	1	2	3	4	5
Defects in:							
- belt loops	_____	_____	1	2	3	4	5
- fly	_____	_____	1	2	3	4	5
- button holes	_____	_____	1	2	3	4	5
Incorrect size tickets	_____	_____	1	2	3	4	5

FABRIC DEFECTS

DEFECTS	DEFECTS AS A % OF TOTAL UNITS PRODUCED	VALUE LOSS DUE TO FABRIC DEFECTS ($ / YEAR)	INSIG-NIFICANT LOSS			VERY SIGNIFICANT LOSS	
Color Variation							
- side to side	_____	_____	1	2	3	4	5
- yard to yard	_____	_____	1	2	3	4	5
- batch to batch	_____	_____	1	2	3	4	5
Visible defects							
- holes	_____	_____	1	2	3	4	5
- stains	_____	_____	1	2	3	4	5
- missing threads	_____	_____	1	2	3	4	5
- warp streaks	_____	_____	1	2	3	4	5
- filling defects	_____	_____	1	2	3	4	5
- spot defects (slubs, neps, etc.)	_____	_____	1	2	3	4	5

FABRIC DEFECTS (cont.)	DEFECTS AS A % OF TOTAL UNITS PRODUCED	VALUE LOSS DUE TO FABRIC DEFECTS ($ / YEAR)	INSIG- NIFICANT LOSS			VERY SIGNIFICANT LOSS	
- pilling	_____	_____	1	2	3	4	5
- reed marks	_____	_____	1	2	3	4	5
- mixed ends	_____	_____	1	2	3	4	5
Width variation							
- yard to yard	_____	_____	1	2	3	4	5
- batch to batch	_____	_____	1	2	3	4	5
Improper finish							
- poor hand	_____	_____	1	2	3	4	5
- not meeting specs for water repellency, etc.	_____	_____	1	2	3	4	5
- printing defects (if applicable)	_____	_____	1	2	3	4	5

TRIM DEFECTS

DEFECTS	DEFECTS AS A % OF TOTAL UNITS PRODUCED	VALUE LOSS DUE TO TRIM DEFECTS ($ / YEAR)	INSIG- NIFICANT LOSS			VERY SIGNIFICANT LOSS	
- buttons broken/ poor strength	_____	_____	1	2	3	4	5
- buttons of wrong color	_____	_____	1	2	3	4	5
- bad zippers	_____	_____	1	2	3	4	5
- bad pockets	_____	_____	1	2	3	4	5
- other (specify)							
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5

MISCELLANEOUS DEFECTS

DEFECTS (please specify)	DEFECTS AS A % OF TOTAL UNITS PRODUCED	VALUE LOSS DUE TO ALL OTHER DEFECTS ($ / YEAR)	INSIG- NIFICANT LOSS			VERY SIGNIFICANT LOSS	
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5
_____	_____	_____	1	2	3	4	5

7. <u>INFORMATION ON QUALITY CONTROL PERSONNEL</u>

   i.   What is the title of the person who is responsible for **fabric/trim inspection**?

   _____ _____ _____

   ii.   How many hours of formal classroom training did they receive? How many hours of on-the-job-training (OJT) did they receive?

   Classroom hours   _____

   OJT hours   _____

   iii. What is the title of the person who is responsible for categorizing **defects in finished garments?**

   _____

   iv.   On average, in your plant, how many years of experience in finished garment inspection does this individual have?

   _____ years

   v.   Does this person usually have previous experience as a sewing machine operator?

   (Y/N) _____

   vi.   How many hours of formal classroom training did they receive? How many hours of on-the-job-training did they receive?

   Classroom hours   _____

   OJT hours   _____

8.   ECONOMIC IMPACT OF DEFECTS: Some specific details related to the economic impact of defects are sought below:

i.   Please list the categories into which defective garments are classified for the purpose of selling and disposal (e.g., seconds, rags, etc.).

ii.   Indicate the approximate percentage of garments that fall into each defect category.

iii.   Estimate the discount by which you mark down these defective garments as compared to first quality garments..

If you do not classify defective garments into different categories for selling purposes, explain how exactly you dispose of these products and state the average value loss suffered on the defective products as a whole.

CATEGORY OF DEFECTIVE GARMENT	% OF TOTAL UNITS PRODUCED	% DISCOUNT VS. FIRST QUALITY
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

COMPANY AND PERSONAL INFORMATION

Neither your name nor that of your company will be published or released to anyone. All the information will be used for analysis only. The following questions deal with information about yourself and your company:

1. Over the past two years, what were the major types (shirts, trousers, skirts, etc.) of garments produced by your company?

2. For each of these classes of garments, please indicate the percentage of your total production volume that these represent.

    Type of garment   % of total production volume

    _____   _____

    _____   _____

    _____   _____

    _____   _____

    _____   _____

3. Company size in annual sales: $ _____, # units:_____

4. Number of employees:

    Production:_____

    Production Support:_____

    Administrative Support: _____

    Management:_____

5. What garments have you, personally, had experience manufacturing -- regardless of where you gained this experience? (shirts, trousers, etc.):

    _____

6. How long have you been involved in apparel manufacturing?

    _____ years.

SURVEY PARTICIPATION AND BENEFITS

i.) Would you like to receive a copy of the survey results? (Y or N) _____

ii.) Would you be willing to participate in a telephone discussion on this topic?
(Y or N) _____

iii.) Would you be willing to attend a group seminar to discuss this topic, assuming a suitable site is found? (Y or N) _____

iv.) Would you be willing to serve on our panel of experts? (This would require that you attend three meetings each year in Atlanta.) (Y or N) _____

v.) Would you be willing to serve as a test site for the software program for analyzing apparel defects while it is in its prototype stage of development? (Y or N) _____

CONFIDENTIALITY

If you answered yes to any of i.) through v.), then we will need your name and address. We would like to know who you are anyway, perhaps because your response may need further clarification in a personal call. Neither your name nor that of your company will be published or released to anyone.

THIS IS CONFIDENTIAL INFORMATION

NAME _____   TITLE _____

COMPANY _____

ADDRESS _____

CITY, STATE, ZIP _____ ____ _____

TELEPHONE (_____) _____-_____

GEORGIA TECH CONTACTS FOR MORE INFORMATION

If you have any questions or need additional information on the questionnaire, please feel free to contact us:

Project Principal Investigator:

> Dr. Sundaresan Jayaraman
> School of Textile Engineering
> Georgia Institute of Technology
> Atlanta, Georgia 30332-0295
>
> ph. (404) 894-2461 or 894-2490 (sec'y)

Research Investigators

> Dr. Krishna Parachuru
> (address same)
>
> Dr. Phiroze H. Dastoor
> (address same)
>
> ph. (404) 894-2494 or 894-2490

THANK YOU FOR YOUR TIME AND EFFORT

ECONOMIC IMPACT OF DEFECTS IN APPAREL MANUFACTURING

QUESTIONNAIRE

AUGUST 1989

Please note: **Neither your name nor that of your company will be published or released to anyone.** All the information will be used for analysis only.

Please return the questionnaire to:

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Tel: 404/894-2490
FAX: 404/894-8780

1)   List three major garment types produced by your company during the past production year. If your company produced only one type of garment, please ignore product numbers (ii) and (iii) listed under Questions 1-5.

        Product No.   Product Type

            i

            ii

            iii

2)   For each of the products identified above, give the total number of first and seconds quality garments (or, percentages of first and seconds quality garments) turned out during the past production year.

Product No.	No. of First Quality Products	No. of Seconds Quality Products
i		
ii		
iii		

3)   Give the figures of average price realization (selling price per piece) for the first and seconds quality products.

Product No.	Selling Price of First Quality Products	Selling Price of Seconds Quality Products
i		
ii		
iii		

4)   Do you believe that the percentage of seconds quality products turned out by your company is in tune with overall industry standards?

        _____Yes   _____ No

If 'No', please indicate the industry standards for the percentage of seconds quality products.

Product No.	Industry Standards for the Percentage of Seconds
i	
ii	
iii	

5)   What percentage of total defects do you believe can be attributed to the two principal sources, namely, fabric quality and sewing performance?

Product No.	Percentage of Defects Attributable to Fabric Deficiencies	Percentage of Defects Attributable to the Cutting & Sewing Process
i		
ii		
iii		

COMPANY AND PERSONAL INFORMATION (will be kept confidential)

1.   Name: _____   Title: _____

        Company: _____   Telephone: _____

        Address: _____

        City, State, Zip: _____

2.   Company size in annual sales: $ _____ ,   # units: _____

3.   Number of employees:

          Production: _____

          Production Support: _____

          Administrative Support: _____

          Management: _____

GEORGIA TECH CONTACTS FOR MORE INFORMATION

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